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COMMUNICATIONS SYSTEMS OVER THE ELECTRICAL POWER NETWORKS

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Master of Science in Networking and Data Communications

THESIS

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Thesis Title
COMMUNICATIONS SYSTEMS OVER THE ELECTRICAL POWER NETWORKS

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Thesis Title: “Communications systems over the electrical power networks”

Project Aims

The existence of the electrical power network gives a great opportunity to have another significant alternative choice to complete the data communication task.

This thesis project aims to present a wide survey of the communications systems over the electrical power networks, including basic theory concepts, limitations, standards, applications and current global market trends.

Project Importance

This project is of great importance according to the expected benefits from using this technology. Currently, this researching area is of great interest since industry invests money according to the demand of using the existing electrical power network as a communication medium.

Many ICT related companies and universities that work over communications systems have dedicated research groups focused in developing and improving PLC technology.

Abstract

Communications systems over the electrical power networks are the core task in this thesis. Current and future needs related to communications systems, lead researchers’ interest to develop several techniques in order have the wanted-needed performance under different available mediums.

In general the technology of transmission data over the electrical wiring is expected to give solutions of great importance to the communication scheme. Their unique advantage is the usage of the existing electrical power network, thus no need of extra wiring installation and of course money saving.

This thesis covers the following: In the first chapter covers fundamental theory concepts, related to communications over the electrical power networks. Additionally, electrical power network fundamentals, PLC limitations problems, security and standardization status will be presented in the second chapter. The third chapter is focused in applications and techniques based on PLC technology. And

finally the forth chapter presents PLC global market trends in relation to competitive broadband technologies, ICT development, current economic crisis and climate change.

Acknowledgements

From the beginning of this Msc Program many unexpected difficulties took place and the fact that I finally managed to complete it makes me feel very happy.

I dedicate my first master degree to my parents and my wife Angelica for their support, patience and understanding.

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Acronyms List

AC: Alternative Current
ARQ: Automatic Repeat Request
ARRL: American Radio Relay League
ASK: Amplitude Shift Keying
BPSK: Binary Phase Shift Keying
BPL: Broadband Power Line
CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance
CDMA: Code Division Multiple Access
DSSS: Direct Sequence Spread Spectrum
DC: Direct Current

DSL: Digital Subscriber Line

EHV: Extra High Voltage

EMC: Electromagnetic Compatibility

FHSS: Frequency Hoping Spread Spectrum

FEC: Forward Error Correction

FTTC: Fiber to the Curb

FTTH: Fiber to the Home

HF: High Frequency

HPLC: Hybrid Power Line Communications

HV: High Voltage

ICT: Information and Communication Technology

ISI: Inter Symbol Interference

LV: Low Voltage

MV: Medium Voltage

OFDM: Orthogonal Frequency Division Multiplexing

PLC: Power Line Communications

RF: Radio Frequency

UTP: Unshielded Twisted Pair

FSK: Frequency Shift Keying

QPSK: Quadrature Phase Shift Keying

QAM: Quadrature Amplitude Modulation

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Chapter 1 "Introduction and basic theory over data communications"

1. Introduction

Digital communications in general deal with data digital transmission over an available medium. Depending on the specific available medium characteristics, analogous transmission, coding and modulation techniques are used in order to achieve the best available communication performance.

As users' demands increased for more advanced digital communication performance and applications, more effective techniques needed to be used to follow market's expectations. All this resulted into today's digital communications systems performance.

Till nowadays the mediums used were either wired or wireless. Recent research and development activities, in the communications systems area, are moving towards another interesting available medium, the wiring used in the electrical power network. Even though it is not new as an alternative communication medium, in recent last years it appears of having great interest for becoming the new medium for digital communications.

As a new medium, the electrical wiring, it had to be examined in order to overcome unpredictable problems. Since at first there was no intention of data transmission usage no prediction took place and medium concerned problems came up. The electrical power network on the other hand, due to its dynamic nature, the more complicated it is, the more it is influencing negatively PLC systems performance.

Researchers at first tried with the available known techniques, from other communication systems like wireless, where there are lots of similarities with PLC channel, to forward PLC technology. In many cases some techniques were accepted, some wanted modifications, while others wanted to be created at first.

Today standardization development on the PLC area has reached a quite acceptable level and main theory tasks have already been identified and examined. Experiments results and industry proposals focus on certain techniques for achieving

an acceptable communication performance under the different PLC channel conditions.

Recent research results and already accepted techniques related to transmission, channel access, spread spectrum, coding and modulation in the area of Power Line Communications are briefly presented in the first chapter.

Taking into consideration that research continues rapidly, the following techniques presentation is updated since the present time and may change whenever better results occur.

1.1 PLC History

The truth is that Power line communications in not a new technology approach. Actually the interest of using the electrical power network for communication purposes started in 1838 with a proposal for remote electricity supply metering. Many years later, in 1897, another proposal showed up referred to a kind of electricity meter via powerline signaling.[1]-[4]

Round early 1900's seems that the interest for applications based on powerline communications was limited [1], till the electrical power network expansion in Europe that took place round 1920, when the interest started to increase gradually. From that moment many application PLC based proposals showed up, basically for controlling, measuring and maintaining the electric power network and making the electric power transmission and distribution more reliable and effective.

Lately, with the liberalization of telecommunications and energy providers' services, the interest of using power line communications applications increased more than ever. Numerous new applications exist since the ability to offer simultaneously internet, communications, multimedia, controlling and energy supply services over the electrical power network gives unlimited potential usages.[1]-[6]

Nowadays, PLC systems are used either for indoor or outdoor applications. Additionally may be used also for broadband internet access, in this case these systems are known as broadband power line systems or BPL. In any case, for economy reasons all communications systems over the electric power lines in this project will be called PLC systems.

1.2 Narrowband PLC Systems

In general narrowband PLC Systems are operating into the frequency range from 3 KHz up to 500 KHz. According to Europe regulations and concerning to narrowband PLC systems, the CENELEC EN 50065 [10] Standard defines the frequency range from 3 KHz to 148,5 KHz. It also defines the restrictions for the allowed power transmission for maximum output, in accordance to the related regulation for EMC considerations [11], which is 5 Volts at 9 KHz and available bandwidth for communication about 86KHz.[9]

Narrowband PLC Systems are used for low speed applications. Either for telemetry and load control applications, like automatic like meter reading – management and load management, or for in house automation solutions. Also these systems may be used in the industry area for automation, controlling and management applications.

Main factors influencing the overall performance of these systems are signal attenuation, interference and noise, which in turn are influenced from other factors like the number and type of the connected loads to the main electrical line and the line distance between receiver and transmitter. [9]

Since restrictions to frequency and power exist, the only way to improve the systems' performance is to choose the appropriate modulation technique for each application respectively. For achieving better results several modulation techniques were used. The final solution came with the usage of broadband modulation techniques [7]. From the first modulation solution, the Amplitude Shift Keying, till the latest one which is the Orthogonal Frequency Division Multiplexing [9], today's narrowband PLC systems achieve data rates higher than ever before.

1.2.1 Modulations in narrowband PLC

The most used modulations in narrowband PLC, according to [8], are:

1. ASK - Amplitude Shift Keying: Due to the fact of not being resistance to interference is not preferred for PLC systems, even if it was used in the first narrowband PLC networks.

2. BPSK - Binary Phase Shift Keying: Because of the phase detection complexity, BPSK based systems are not used so much. Meanwhile systems based on BPSK are widely used in accordance to the FSK usage for narrowband PLC systems.

3. FSK - Frequency Shift Keying: Among the best modulation techniques for narrowband PLC systems.

4. QPSK - Quadrature Phase Shift Keying: Related to QAM, is less powerful.

5. QAM - Quadrature Amplitude Modulation: It offers signal keying modulation, and increased transmission. Its drawback, it has less resistance to interference.

1.3 Broadband PLC Systems

In general broadband PLC systems are providing much higher data rates than the narrowband ones. Their characteristic ability to provide more completed communication services allowing multiple users to communicate over high speed data transmissions, while simultaneously can provide solutions for narrowband PLC systems and improve their performance, make broadband PLC systems of great significance.

Despite the additional factors influencing negatively these systems, like EMC, selective fading, interference and the limitations into the power transmission in order to reduce EMC, the solution for better performance results is given by the implementation of spread spectrum techniques. Recent research results leaded towards the OFDM solution, which can improve performance and provide much better results.

Broadband PLC Systems are used into both MV and LV networks, for outdoor and indoor applications. For the case of MV networks their usage is to provide point to point connections by covering long distances with the appropriate equipment installed. Another utility of these systems is to cover the connection of local area networks between buildings and even extend existing networks by using hybrid PLC solutions. Finally their ability to provide high data rates despite the existing limitations, make them become an important candidate for providing the last mile solution for communication access network.[7]-[9].

1.3.1 Modulations in broadband PLC

The most used modulations in broadband PLC, according to [8], are presented as follows:

1. OFDM - Orthogonal Frequency Division Multiplexing. It is a transmission technique working with a spread spectrum. The signal is transmitted to more independent frequencies, which increases resistance to interference.

2. DSSS - Direct Sequence Spread Spectrum. The signal is spreading into more parts of the radio spectrum, it is less sensitive to interference which in turn increases the reliability of transmission.

3. FHSS - Frequency Hopping Spread Spectrum. This is a method of transmitting by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence.

1.4 Transmission Techniques

1.4.1 Orthogonal Frequency Division Multiplexing-OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is the first choice, by now, transmission method used in power line communications, as it is used widely in standardization and production. Its implementation idea come up from the wireless communications area, where is used as the most promising transmission technique and is already accepted for standardization and applications. [12]-[23]

OFDM is a frequency division multiplexing, FDM, scheme used as a digital multi-carrier modulation method. Actually it divides the available bandwidth into a number of sub carriers and every one of them behaves like an independent channel for the data transmission. All these sub carriers are orthogonally spaced and are used to carry data, so data is divided into several parallel data channels, one for each sub-carrier.

The orthogonality mentioned, means that distance between sub carriers is so close, almost overlaps one another, resulting to the elimination of interference, hence no inter symbol interference appears.

Each data stream can be modulated variously and independently by using modulation schemes like QAM or PSK. The modulation method used, its coding rate and the coded bits number per sub-carrier define the supported data rates.[24]-[32]

Sub-carriers orthogonality prevents others, on the demodulator side, from seeing others' frequencies. An applied Fast Fourier Transform, FFT, solves the problem on the demodulation side to extract the transmitted data for each sub carrier.

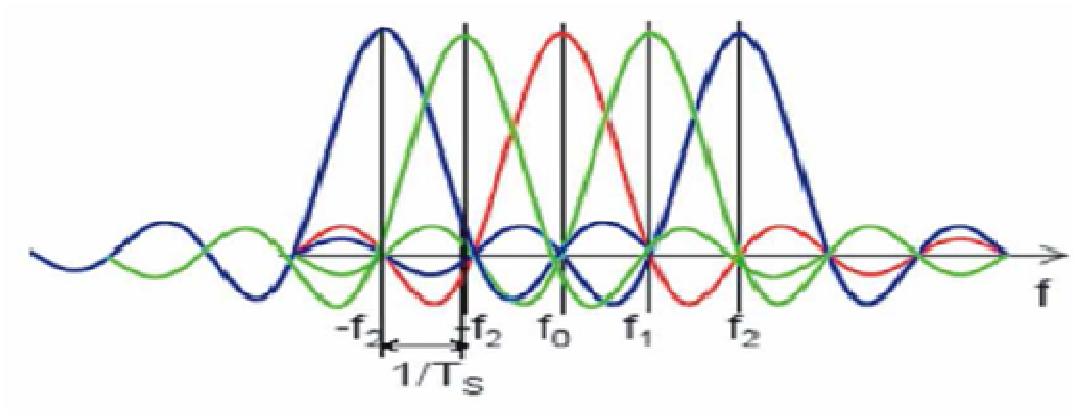

Figure 1.1: 5 sub-carrier OFDM spectrum

Among the OFDM advantages consider the following: 1) simple and low cost implementation, 2) every sub-carrier is noise, inter symbol and frequency independent, 2) robust against inter symbol interference, narrow band sub channel interference and fading due to multipath, 3) requires less bandwidth for data transport and can cope with attenuation caused by high frequencies.

While OFDM's main disadvantages are its sensitiveness to frequency synchronization and to Doppler Shift. For more details over OFDM available in [9],[33]-[37].

1.5 Channel Access Methods

1.5.1 CSMA / CA

Additionally, as it seems in table B1 and [12]-[17],[38] the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) method is also widely used, almost in all accepted PLC standards, as an access method.

In general with CSMA/CA, the network's performance is improved with the use of collision avoidance, (CA) since its employs a carrier sensing mechanism which shows whenever there is traffic not in the network. Actually it works by preventing collisions rather than waiting them to take place and act after.

More precisely, a station before transmitting has to listen first to the channel whether another station is transmitting or not. If the channel is busy then the station

starts its transmission after a random period of time and if the channel is idle then the station starts the transmission. If a station while transmitting, detects a signal from another station, it stops transmission and after a random period of time repeats the above mentioned process.

Its low cost implementation and the performance improvement over data rate are the two main advantages this medium access method provides.

1.6 Multiple Access Methods

In general there are three basic methods providing multiple access for all communications systems. These methods are 1) Time Division Multiple Access (TDMA), 2) Frequency Division Multiple Access (FDMA) and 3) Code Division Multiple Access (CDMA). For the case of PLC all these methods or combinations of them, are widely used.

1.6.1 Code Division Multiple Access (CDMA)

While time division multiple access (TDMA) and frequency division multiple access (FDMA), use time and frequency slots respectively, to assign different users, code division multiple access (CDMA) uses individual data streams that are encoded with pseudorandom sequences and transmitted over the available spectrum. So CDMA users are using the same band at the same time. Its drawback is each user's amount of noise to the other users' receivers, which brings limitations to the user's number of a CDMA system.

CDMA signals can be modulated either by frequency hopping, time hoping and direct sequence modulation techniques, which in turn form the FH-CDMA, TH-CDMA and DS-CDMA solutions respectively. Further combinations of these solutions lead to hybrid CDMA like DS/FH CDMA and FH/TH CDMA [9].

In general combinations of the above mentioned CDMA based solutions can also be implemented, since they have better performance results, depending on characteristics of the available transmission channel [39].

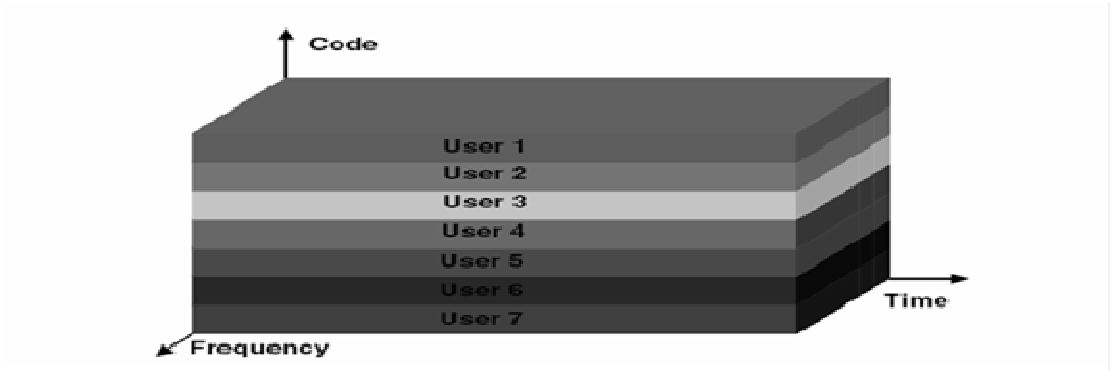

Figure 1.2: CDMA

1.7 Spread Spectrum Techniques

Spread Spectrum Techniques are used in order to avoid interception, multipath distortion and jamming by spreading the data transmitted into a wider bandwidth. Also signal encryption and hiding are affordable and last of all but not least, the capability to allow multi users to share the same bandwidth by limited interference. The benefits mentioned may not valid all together for all spread spectrum techniques but undoubtedly conclude the whole of their benefit capability.

Basically the data to be transmitted is modulated by a spreading sequence, which sequence usually comes from a pseudorandom number, or pseudo noise, generator. More bandwidth is required after the spreading process since the initial data is being spread. The spreading factor, comes from the ratio of transmission bandwidth and the original bandwidth, determines the chip number needed for spreading one data symbol. The spreading sequences are separated into orthogonal and pseudo noise. In general cross correlation between them is quite low and in case they are orthogonal, cross correlation is zero.

Two basic types of these techniques are widely used in the area of communications and power line communications, the frequency hopping and direct sequence [7],[42]-[45].

1.7.1 Frequency Hoping Spread Spectrum (FHSS)

The mechanism is to broadcast the data signal over a random frequency set, hopping from one frequency to another at predetermined intervals. Transmitter and receiver must be synchronized. The advantages of FHSS are: resistance to

narrowband interference, efficient bandwidth usage and difficult signal interception [7].

1.7.2 Direct Sequence Spread Spectrum (DSSS)

Direct Sequence Spread Spectrum (DSSS) is widely used in communications systems. It contributes to interference reduction by averaging it over large time intervals. Spreading codes are used to multiple the data signal to be transmitted into the transmitted signal. It uses pseudorandom sequences to modulate the data to be transmitted. The overall bandwidth of the transmitted data signal is higher than the one being modulated. Several single carrier modulations like QPSK, BPSK or M-PSK and others can be used [7].

1.8 Error Control Basics

PLC systems are suffering from many difficulties that occur even due to the medium and electrical power network characteristics or due the frequency and power transmission limitations by the world wide regulations.

In any case, as happens in all communication systems, additional techniques are used to overcome the difficulties that occur during the data transmission. Among the most well-known and effective techniques used are Error Correction, Automatic Repeat Request and Interleaving [7],[53]-[55].

1.8.1 Forward Error Correction Mechanisms

Forward Error Correction Mechanisms are used worldwide for improving the digital communications systems performance, by protecting the data information from the disturbances that occur due to the medium effects. Their operation is based on the additional data information, into the original data to be transmitted, which is used from the receiver to recognize and correct whether transmission errors occurred.

Depending on the channel characteristics and the existence of several different codes, the communications' system transmission performance may be improved when implementation of the suitable code take place.

As it is known in practice the theoretical channel capacity limit and the practical result differ quite a lot, but that is why is of great significance to implement the

suitable code since there is much more additional system performance improvement available.

In general the error correcting codes can be divided into two subcategories, the block codes and the convolutional codes.

Block codes may be sub-divided into two basic categories, the binary and the non-binary codes. Consider as the most popular of them, for the first category the Cyclic and Hamming codes and for the second category the Red Solomon codes. And Convolutional codes are widely used in communications in order to provide reliable data transmission [7], [9], [46]-[48].

1.8.2 Automatic Repeat Request Mechanisms

The ARQ mechanisms are used in data networks where reliability of received information is of great importance and delay is less of a problem compared with real-time multimedia applications.

In general, when using ARQ mechanisms, if a block of data is received in error, then the receiver requests retransmission of the block of data. Usually, an acknowledgement packet is employed to indicate correct reception of one or more transmitted packets. If an acknowledgement is not received in a certain time frame, or a negative acknowledgement is received, then the transmitter will retransmit the packet.

There are three basic ARQ mechanisms.

1. The send-and-wait ARQ mechanism waits for an acknowledgement for each individual packet before sending the next one. This is especially inefficient if the round-trip times are large, because the transmitter spends a lot of time waiting for the acknowledgement.

The procedure followed is when the acknowledgement is positive then the transmitter forwards the next data packet. And if the acknowledgement is negative then the transmitter forwards again the same data packet.

2. In order to improve the delays of the send-and–wait ARQ mechanism, the go-back-N ARQ mechanism is used to transmit multiple data packets, up to N, at a time and waits for acknowledgement for all these packets. Also, it is possible to acknowledge these packets with one response.

Depending on the receipt of acknowledgements the procedure is as follows. If the transmitter receives positive acknowledgement it will consider that all data packets, till the positive acknowledged one, are all correctly been transmitted. And if the transmitter receives negative acknowledgement for a certain data packet it has to retransmit it again with all the following, after that, data packets.

3. The selective-reject ARQ mechanism is used to avoid the drawbacks of the other before mentioned ARQ mechanisms. In this case only those packets that are received in error are retransmitted. The result is that this mechanism provides better data throughput [7].

1.8.3 Interleaving

Interleaving is commonly used in telecommunications, as error correction mechanism, in order to increase system's performance. At the transmitter side it works by changing the data symbol's order before the transmission take place. And as this data is being de-interleaved at the receiver's side, if an error occur several code words are responsible for recovering the erroneous symbols. The number of the errors that can be recovered is depending on the capability of the error correction code [7].

Chapter 2 "Fundamentals of Communications Systems over the Electrical Power Networks"

2. Introduction

Fundamental aspects of communications systems over the electrical power networks are contained in the second chapter. A division into three topics takes place, in order to simplify the presentation.

The first topic is related to communications Systems over Electrical Power Networks. As PLC systems use the wiring of electrical power network, fundamental aspects of this network are presented. Additionally, PLC system's basic components and their operation characteristics are briefly explained.

Many reasons, of different origin, make problems to PLC systems' performance. These reasons are contained into the second topic which is called limitations, and are distinguished into noise and electromagnetic compatibility. Additionally the crucial tasks of channel modeling, coupling and security are taking into consideration.

Finally, PLC standardization development is covered in the third topic. Main involved bodies into the standardization progress, industrial and international PLC standards either already approved or forthcoming are also presented.

2.1 Electrical Power Network Fundamentals

In general the term electrical power network system refers to the concept of energy production, transmission and finally distribution to the end users.

Generating stations or power plants are called the places where electric energy production takes place. And the energy transmission is completed with the use of power lines carrying the energy into the form of current either AC or DC for reliable, safe and economic energy transfer.

A three phase AC technique is the most commonly used for the energy transmission. Each country, depending on the geographical coverage, it's economic and industry development employs advanced techniques to improve the energy transmission concept. Some basic operation characteristics are in common use or

have relative difference. In example the operation frequency, which is of great significance and its value is 50Hz for the countries of Europe, Asia and Australia, while in U.S is 60 Hz.

The energy produced has a voltage value that is not suitable for long distance transmission. The solution is given by the use of a transformer by which the voltage value is increased and according to the Ohm's Law the current is reduced. This technique is mainly used for energy transmission over power lines since it provides reliable and economic energy transfer.

In general, the transmission lines maybe overhead or underground depending on the environmental circumstances and the available finance budget. There are three types of these lines, each one with its one operation characteristics.

Starting with the high-voltage and extra-high-voltage (EHV) transmission lines, these are used to forward the electric energy produced and connect the generating stations with the end users. The available voltage rate may be between 115 KV and 800 KV. These lines may use either AC Current or DC Current. Usually the maximum covered distances of high voltage transmission lines is around 200 miles, while for the extra high voltage transmissions lines is around 400 to 500 miles.

Also high voltage direct current (HVDC) lines belong to the first type and are used for long distance distribution due to the benefits they provide. Their unique advantage is the ability to transfer oven very long distances large energy amounts, with significantly lower cost and losses.

The second type is the typical sub-transmission lines that interconnect the high-voltage substations with distribution stations within a city. The voltage of the sub-transmission system is between 46 kV, 69 kV, and 115 kV. The maximum length of these lines is estimated to 50–60 miles.

Distribution or low voltage lines are the last type and their role is to provide the energy to the end users. The voltage of the distribution system is between 4.6 and 25 kV. Distribution feeders can supply loads up to 20–30 miles [49].

2.1.1 Power Grid Problems

In general the problems that occur into the electric power network influence the data transmission performance when these lines are used as power line communications networks.

Problems occur due various reasons, either because of technical aspects or because of physical phenomena like weather conditions and tree falling.

As it concerns the technical aspects, the electrical power network system consists of several components that have special usage utilities and operation characteristics. Every component has by manufacturer a failure probability. The reliability of the transmission and distribution system relay on the failure probability mentioned before. System main components are transformers, cables, poles and circuit breakers.

Serious grid problems often appear either due to physical phenomena or due to power quality issues and even equipment failures. These numerous influencing factors, concerned to physical phenomena, can be divided into two sub categories. The first refers to human factors that may be intended or unintended human actions. And animals, extreme weather conditions, physical disasters and trees apart the second sub category.

While the most widespread power quality problems are caused from voltage sags and momentary interruptions. And among the most common events that can fail equipment consider over voltages, poor grounding, capacitive coupling, inrush current and unbalanced sags [49]-[52].

2.1.2 Transformers

Transformers are among the main key components for the electric power network. Their first responsibility is to step up the voltage value in order to achieve the electric energy transmission for long distances with fewer losses. And their second responsibility is to step down the voltage value to make the electric energy available and ready to use from the end customers, on the distribution process.

These are called distribution transformers and are available into several different standards depending on the total voltage amount that can be transformed and their operation mechanism.

2.2 PLC Components

In every communication system, whatever medium is used, either wireless or wired, specific components are used. For PLC systems, the essential minimum components are injectors, extractors, repeaters and modems [2], [37], [53].

2.2.1 Injector – Extractor

Injector is the device used to provide the way to data information to enter into the electrical power network system. In other words, it works by providing the necessary input connection to the MV or LV electrical network. Its input may be connected with the internet backbone network by all available known solutions like wireless, fiber optic or T1 line.

The received data information then is transformed into the appropriate signal format in order to entry into the electrical power network.

An injector may contain a transmitter, a receiver and a signal converter. Bidirectional operation is available for full duplex transmission over the power line electrical network.

The extractor is appropriate in order to provide the interface between MV or LV and end customers like small business or homes,. Many different available operations may be added into extractor's operation panel. It may include repeater functions and may provide interface for non PLC networks, such as wireless, which in turn expands networks coverage area depending on the circumstances.

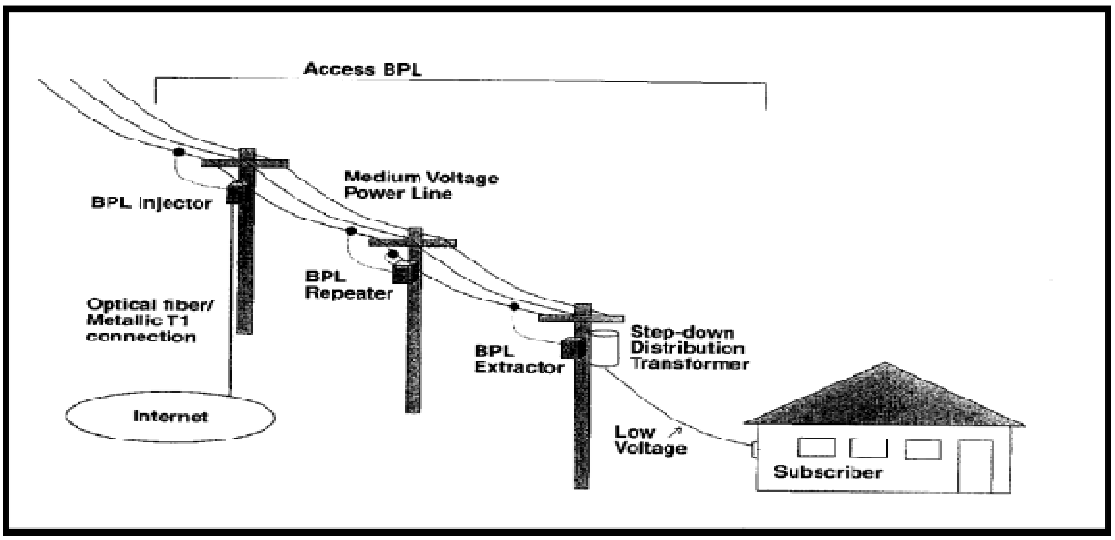

Figure 2.1: PLC Access Infrastructure

2.2.2 Repeaters

Repeaters contribution into the overall PLC network performance plays a critical role since their purpose is to stabilize and amplify the data information carried into the electrical power line network.

Since distances between PLC end users and base stations are too long, data signals suffer from attenuation and distortion. The solution is given by the repeaters implementation and their responsibility is to take and forward data information at the correct data transmission level.

Depending on applied transmission and modulation methods, the repeater function can include demodulation and modulation of the transmitted signal as well as its processing on a higher network layer.

However, the application of repeaters also increases the network costs because of the increasing equipment and installation costs. Therefore, the number of repeaters within a PLC access network has to be kept as small as possible.

2.2.3 Modem

The modem is the last equipment component that is used for connecting the end user devices with the PLC medium. This connection can be done with every available coupling method, either capacitive or inductive.

Additional ports may also be available on the modem device either for telephony usage purposes or for additional communication devices [2], [7], [53].

2.3 PLC Limitations

2.3.1 Noise

Among the most important negative influencing factors is noise. The electrical wiring as a medium is a very noisy environment and unfortunately causes severe problems into PLC systems performance. Many attempt ions to clarify the noise characteristics and how it is influencing PLC performance, have been made [54], [9].

In order to understand how noise works, a description is used in [7], which specifies five noise types, that exist over PLC channels, according to their origin, time duration, spectrum occupancy and intensity. The overall noise comes as a superposition of these noise types.

The first type is the colored background noise which is a superposition of several different noise sources of low intensity. Induction heaters, inverter driven fluorescent lamps and front-end amplifiers of receivers are its representative sources.

Narrowband noise is the second type which is produced due to the interference caused from wireless and broadcasting communication stations over medium and shortwave bands. Since PLC systems use frequency bands nearby those who are used by the above mentioned systems, they suffer from this type of noise.

It is considered that the switching power supplies are mostly responsible for causing the third type of noise which is called periodic asynchronous impulsive noise. While periodic synchronous impulsive noise, the forth noise type, is mainly caused by power supply operating synchronously with the main frequency, such as the power converters connected to the mains supply. Finally the last fifth type is the asynchronous impulsive noise which in turn is caused by switching transients in the networks

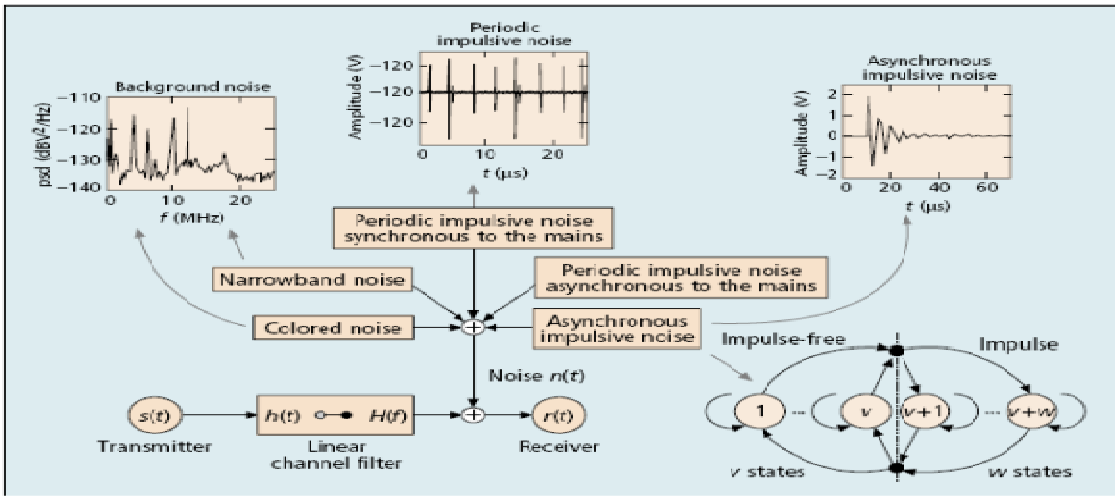

Figure 2.2: Noise types in PLC environments

2.3.2 Electromagnetic Compatibility - EMC

The development of PLC Technology and its impact in the communications market is strongly depending on the solutions given for the task of Electromagnetic Compatibility.

Since the available medium used is not designed for transmitting data, therefore several problems occurred from PLC usage. The electrical wiring, used either indoor or outdoor, has specific operational characteristics to comply with international

regulations for safe, productive and costless energy transmission and distribution. But unfortunately for the PLC case, no provision for data transmission usage is predicted into electric wiring characteristics.

In fact PLC performance is influenced by EMC not only due to the medium characteristics but also network topologies, weather conditions and devices used within the general powerline network have a merit in the EMC production.

On the other hand PLC influences other applications existing in the environment near the power lines which are using the RF spectrum and causes severe problems into their performance.

At this point it is worth saying that PLC networks are not radio networks even if their operation influences the latter. But as regulation bodies related to telecommunications see PLC as being a radio network, it has to follow and comply with the restrictions for frequency band usage and data transmission power.

Despite researchers' attempt ions and worldwide regulation efforts still no final acceptable solution is found for the case of PLC. Meanwhile standardization bodies are developing new standards to define the acceptable EMC details for the PLC case, so different technologies using RF not to interfere each other.

2.3.2.1 HF Radio spectrum

High speed PLC uses the part from 1 to 30 MHz of the frequency spectrum. According to the radio signal operation properties, in this frequency range, many significant communication capabilities exist due to the signal properties and are of great significance to avoid their existence. Among them the ability to transmit data over very long distances with very little power needs and with no need of repeaters.

The whole matter with EMC is the fact that PLC uses frequency bands that are either near those used by sensitive applications or near others excluded tables B7-B8. In practice many radio user categories are influenced, like amateur radio, broadcasting, aeronautical and marine communications.

In any case, the usable and permit able frequency range of PLC is a matter for the authorized regulation bodies. The needed frequency restrictions are already in issue since 2004 by FCC Regulations [55].

2.3.2.2 Influencing Factors

The influencing factors can be divided into two subcategories, the first is related to the medium characteristics, which makes PLC the source of EMC production and the second is related to the power line network components, which makes PLC to suffer from EMC.

2.3.2.2.1 Medium Characteristics- Extra Interference

Researchers results show that medium characteristics, either they are used in MV or LV, are responsible for EMC production and radiation. In any case EMC interference is present and makes severe operation problems into the nearby radio applications.

When the PLC signal operates in the range of 1 to 30 MHz, electromagnetic emissions occur and disturb the environment nearby the power lines, so other radio users suffer from EMC.

The main factors responsible for the EMC production are wiring characteristics and shielding.

The wiring characteristics do not provide the essential symmetry to overcome the EMC production, as happen with UTP or twisted pair wiring used for wired communications.

And unshielded power lines do not provide EMC protection to the nearby radio users. The medium acts like an antenna when used for data transmission, which makes the produced amount of EMC a severe by radiation influencing factor. It causes greater interference when the distance from power lines is small. As this distance increases the interference is reduced [55]-[57].

2.3.2.2.2 Power Line Network Components- Intra Interference

As it is difficult to examine all topologies and components, main conclusions can be taken, considering the available researchers results, for the influencing factors of EMC production and affect into the PLC performance.

Different power line network topologies with different loads and operation characteristics produce a quite large amount of noise. In general devices like

switched power supplies, frequency converters, transformers and switches when are connected to the electric power network are producing impulse noise.

Another influencing factor is attenuation which is caused due to several reasons like the wiring structure of the power line network itself. As the medium route changes from overhead to underground and vice versa, considering and the necessary interconnections, signal attenuation occurs.

Additionally attenuation of the signal strength is added due to the high frequencies used and the wiring characteristics. As it is known high frequencies suffer from greater attenuation comparing to the lower frequencies. Also the wiring distance and the wiring characteristics like resistance, inductance and capacitance contribute to signal attenuation [55]-[57].

2.3.2.3 The Problem According to ARRL

The American Radio Relay League (ARRL) is a worldwide organization of amateur radio operators. Maybe is the most known group against PLC spreading, based on the interference caused to licensed services and basically amateur radio. The efforts on behalf of ARRL are pushing FCC to define strict limits and restrictions for PLC in order to minimize the interference levels it produces.

More precisely there is an overlapping between the authorized PLC frequency bands and those bands which are used by the radio operators. Tables B7-B8. Initially many complaints were made from radio operators' side, since problems occurred from the PLC usage.

Attempt ions to calculate the overall disturbances made from PLC usage, showed the main problems that occurred where: 1) the operating frequencies used from PLC, 2) the EMC production and 3) the noises interference because of the spread spectrum transmission technique [6].

2.3.2.4 Limiting EMC

Standardization activities for the PLC/EMC matter are already ongoing. The questions, they are calling to solve out, are how to use and manage power transmission and frequency spectrum. Two known limiting EMC methods are notching and transmission power.

Notching is called a set of frequency filtering techniques designed to overcome the problem occurred from the coexistence of different technologies when using the same frequencies of RF. Actually the frequencies are listened and those which are in use by other applications ,are taken away.

According to the FCC rules the unlicensed transmitters like PLC, have to protect the already licensed services. In other words the interference caused by licensed services is acceptable from the unlicensed, but the opposite does not count.

In this case PLC has to overcome the interference problem that causes to other RF systems. The power used for data transmission over power lines is related to the produced interference. The larger is the power, the larger is the interference. A solution can be given by limiting the power needs for data transmission over the power lines. But since lower transmission power means lower interference, it also means lower data throughput, so another solution has to be found. The use of immediate repeaters is the solution, which gives PLC the opportunity to transmit data with limited power usage and resulting in limited interference production [6].

2.3.2.5 Regulations - Standards

In general the frequency bands used by PLC are divided into those of low speed and those of high speed technologies. For the first case the band is from 3 to 148 KHz while for the second case the band is from 1 to 30 MHz.

At first and as the operation of PLC was frequency limited, under 490 KHz, and there was not such disturbance since the regulations covered the subject and interference did not bother so much. According to the regulations, unlicensed emitters are allowed to exist under certain conducted and radiated emissions.

The regulations predicted for using power lines to conduct signals, as it happen with FCC CFR 47 Part 15. But as PLC development leaded to high frequencies usage, it was the time when the EMC theme raised.

Finally, nowadays regulations bodies are working on improving the regulations, according to the existing needs. Of course FCC plays critical role in this effort but also and other organizations are willing to help, like IEEE.

The IEEE P1775 standard is still under development the formal title of this standard is: “Standard for Powerline Equipment – Electromagnetic Compatibility (EMC) Requirements –Testing and Measurement Methods.”

Its development is crucial for the future of PLC technology, since there is no other standard or regulation that addresses the tasks of EMC due to PLC, coexistence and interoperability. All participators of PLC technology including industry, investors and market are aware of the final approved standard [58].

2.4 Channel Modeling

As power line networks are not designed for data transmission, PLC systems are facing various and serious challenges that are influencing negatively the communication concept. The truth is that it is quite difficult to recognize and overcome all disturbances that may occur.

Consider among as the most serious effects, related to the power network: **1.** Topology characteristics like line and branch length, branch number and load impedance, **2.** Electrical network components, **3.** Medium characteristics, **4.** Interconnections and **5.** Transformers

In any case a lot of work has been done already in order to understand and calculate the above mentioned effects and how to overcome them. Some indicative work is available in [59]-[63] and further information in [9].

So in order to simplify PLC systems design and improve their performance results, it is essential to use behavioral prediction tools over the available communication network, under certain network topology and load conditions. As it happened for the wireless communications case, the best idea is to use channel modeling.

The procedure is to estimate and predict power lines network response and effect into PLC systems performance, by taking into consideration possible different PLC channel conditions and recognize the disturbances they suffer from. Finally researcher’s interest leaded to numerous channel modeling proposed solutions, like [64]-[69] and [9] for more extended analysis.

A worth mentioned proposal came from the Open PLC European Research Alliance, OPERA, which defines reference channel models for broadband access PLC systems and in- house PLC networks.

For the broadband access case, nine reference channels are designed on the basis that represent real LV channel characteristics and cover three classes of distances, each one containing three quality levels. These distances are short, medium and long with the estimation that each one covers about 150m, 250m and 350m respectively. The quality levels are taking into consideration branches, multipath and attenuation, and are defined as good, medium and bad quality level.

For the case of MV channels the estimation is that can be addressed as another scenario of the access case and can be predicted with the above mentioned reference channels. The estimation of MV channels' behavior is better than those of LV as it concerns attenuation and multipath.

Accordingly the same work is done for in house PLC networks, taking into consideration their networks small coverage area and whether these networks are operating in private or commercial buildings [70].

2.5 Coupling

Medium accessing is of great significance for PLC technology since it determines the overall communication system performance. The scope is to provide a secure and reliable method to connect PLC equipment to the electrical network, while simultaneously keep the expecting best effort performance of the system.

However severe problems occurred related to fact that the existing electrical power running through power lines is number one enemy for the sensitive PLC devices, that are about to be connected to the electrical network.

Researchers' experiments finally leaded into two solutions that provide safe and productive connection between PLC devices and the electrical network. The project is called coupling and the solutions are either capacitive coupling or inductive coupling.

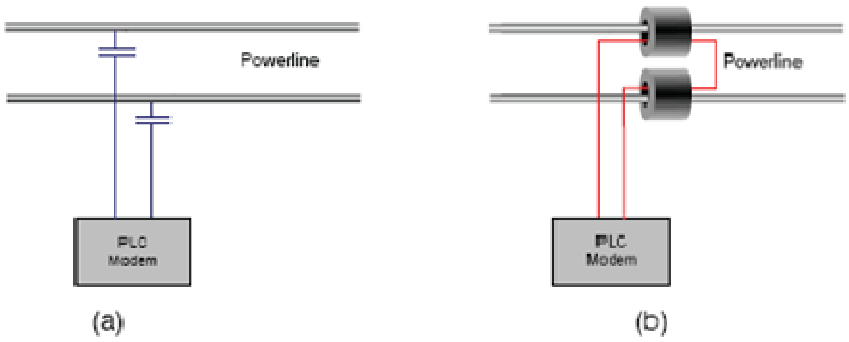

Figure 2.3: Connection in a case of (a) capacitive coupling and (b) inductive coupling

In general, from the electrical engineering perspective, coupling is referred to the connection between two different electrical circuits resulting into the electric flow production within those two circuits. Basic electro-magnetic field characteristics relating with the circuits capacitive or inductive nature, form the final result.

Devices of specific design and certain functionality abilities called couplers are used to provide the essential medium access. A coupler device defines the overall performance of the hypothetical PLC system. Its design and functionality abilities play critical role as antennas do for the case of wireless communications. A coupler is designed to enter and extract data into/from the electrical power waveform and to prevent from entering the electrical power into the sensitive PLC modem.

Additional coupler properties like frequency filtering and protection from electrical circuit malfunctions are also available. While frequency filtering in this case is the frequency selection ability, in order to reduce noise or EMC and improve SNR.

2.5.1 Capacitive coupling

The most used coupling solution for PLC systems. Widely used as it provides an economical implementation over LV PLC applications. It provides a direct connection to the electrical power network, as it only needs the PLC modem to be connected to the electrical outlet.

Capacitive coupling is used when inductive coupling is not possible due to the geometry of the couplers, due to too high current ratings, etc. In the case of LV

networks, capacitive coupling is always used since inductive couplers with suitable dimensions and saturation currents are not yet available.

Neutral and live electrical cables are used for capacitive coupling, since by doing this it is secure that all connected loads are taken into consideration. And since capacitive coupling requires direct connections to conductors, the electrical power is switched off whenever possible for installation. For the cases when the power cannot be switched off, the installation is dangerous.

2.5.2 Inductive coupling

For this case no direct connection to the electrical power network is needed, thus inductive couplers are electrical insulated. The idea is to use the electromagnetic field characteristics, due to the electrical current movement and benefit from their results by placing the necessary PLC equipment.

A ring shaped magnetic coil is placed around the electrical power cable or around the neutral one. Actually, inductive coupling installation depends on the available electrical power network topology, if it is a single or three phase network. So since magnetic coil placement is influencing the PLC system performance, it is under research whether to choose the appropriate coupling placement.

In general inductive coupling is a more preferable solution depending on the specific available electrical network conditions, for example places where electrical power cables are not visible or are insulated. When is about substation installation is the preferable solution. In general it is considered to be more efficient than capacitive coupling [2], [9].

2.6 PLC Security

In general, communications systems are secured by the science of cryptography, which also known as encryption. The basic services that encryption provides are confidentiality, authenticity, integrity and non-reputation. In brief confidentiality means no access without authority, while authenticity refers to identification of the network participants. Accordingly integrity is used for securing that the transmitted data is not modified and finally non repudiation provides information when a message was sent and when it was received.

All in all encryption does is transforming the original data into a different data that cannot be readden without the key. In other words encryption relays on this key which, on turn, is relaying on its length of bits. Key's length is analogous to the security it provides. But in any case, depending on the invader's capabilities and their time availability, almost all encryption keys can be broken.

There are two basic techniques for encryption keys. These are symmetric or private keys and asymmetric or public keys. Symmetric keys are used mostly and provide confidentiality but cannot provide non repudiation and authentication. Their long length makes it difficult to be broken and provide faster speeds. While asymmetric keys require a private and a public key in order to be formed [71].

As it concerns PLC systems network security, these are considered as wireless networks, since the difficulties that occur, are some kind similar complicated. Even if PLC medium access is quite difficult and the presence of AC current 240V/50Hz or 110V/60Hz is severe danger to avoid, unwanted network attacks await and solutions have to be employed. These unwanted attacks may have various types like unauthorized access, eavesdropping, data manipulation, operation interference and many others. The response to these attacks is to use advanced network security techniques [6], [72].

Researchers' proposals, [73]-[76], showed that since PLC systems are used for indoor, outdoor and broadband applications their security status is depending on the network's coverage, how these are influenced from outer factors and the devices connected to the network. Their proposals leaded to the conclusion that depending on the PLC applications used different security mechanisms are suitable.

Latest basic industry standards for PLC systems, like HomePlug 1.0, HomePlug Turbo, HomePlug AV and UPA (DS2), are using encryption keys like NEK, NMK, DAK, TEK, with 56 or 128 bits length for securing these systems [6], [72].

On the other hand recent efforts in the standardization area and especially the forthcoming IEEE 1901 Standard, for Broadband over Power Line Networks Medium Access Control and Physical Layer Specifications, is expected to address the security task for broadband PLC systems.

Finally, despite the above mentioned efforts for securing PLC systems, these systems are considered secure depending on the circumstances under which they

operate. The fact is that despite the already existing security solutions, the security task for PLC systems has left behind in relation with other sectors and needs further exploration [72].

2.7 PLC Standardization

2.7.1 Standards-Organizations

According to the definition given by ASTM a standard is a common language that promotes the flow of goods between buyer and seller and protects the general welfare. In the standardization development, standards are divided at least into five categories depending on the acceptance and use they need. These categories are company, consortium, industry, government and voluntary standards [77].

Standardization development in PLC has been influenced from all the above mentioned standard categories. Due to the specified characteristics of PLC technology and the fact that power lines operation details defers from country to country, many different approaches have been made for the standardization development of PLC.

Starting from the early years of research over PLC standards till today, a great number of industrial companies, universities, governments and volunteers have proposed interesting solutions. Industry companies manufacture already PLC equipment based on their standards and several applications are on run successfully from years [78]-[80].

Current standardization development of PLC can be divided into two categories: The first category refers to International and Industrial Standards, from the early years till today, including forthcoming standards. And the second category contains main International and Regional Standardization bodies that participate in this development.

2.7.1.1 International Standards

Among the existing International Standards some are already accepted and published, while other are about to be published in near future since researchers' results promise so.

As the list of the already accepted standards for PLC is quite long, an indicative presentation containing standards of great significance follows.

IEEE 1901: The formal title is Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications.

This Standard is still under development by the IEEE P1901 Working Group, and is developed for high speed communication BPL devices with speed greater than 100 Mbps and transmission frequencies below 100 MHz at the physical layer.

According to official announcements several crucial tasks are solved. More precisely with the implementation of coexistence and interoperability mechanisms, it provides balanced and efficient use of the available communication channel and quality of service and bandwidth as desired. The security task which is of great significance for security sensitive services is also addressed. The EMC regulations according to the accepted limits are set and no interference exist between different applications and technologies used. Last but not least the interoperability matter with other networking protocols used is finally solved. It is expected to be the standard that will take off the PLC Technology [81]-[82].

IEEE P1675: This standard is already approved and published. The formal title is Standard for Broadband over Power Line Hardware. According to its purpose production, it provides testing and installation standards on hardware used with the PLC systems and installation methods for ensuring the compliance with applicable codes and standards.

High speed data transferring, by safe protection and operation, from the substations into homes is also available. It determines the specifications of hardware used so that correct operation is achieved. The mentioned hardware includes injection and extraction couplers and enclosures.

According to the Chair of the Broadband over Power Line Standards Working Group, power utilities and BPL industry have the ability to confidently pursue a BPL connection, which ability is given thanks to the IEEE 1675 Standard [83].

IEEE P1775: The formal title of this standard is Standard for Powerline Equipment – Electromagnetic Compatibility (EMC) Requirements –Testing and Measurement Methods and is still under development.

According to its scope, electromagnetic compatibility (EMC) criteria, testing and measurements procedures for equipment and installations for broadband over power lines are addressed. Taking into consideration national spectrum regulations provides guidance relevant to the power and frequency usage on behalf of PLC Technology.

Existing national and international standards are used as reference for this standard for PLC equipment and installations [84].

ITU-T G.9960: This Standard is part of the G.hn series started by ITU-T and is promoted by many organizations working in the area of home networking.

The idea is to develop standard series that support home networking over all the types of wires existing in home. These wires might be power lines, phone lines and coaxial cables.

The G.9960 Standard is already approved and specifies the physical layer and the architecture of G.hn. Basically the G.hn series are promoted as to be the next generation standards for home and public places networking. [85]

2.7.1.2 Industrial Standards

Industrial standards production comes from companies, either industrial or individual, proposals into a certain technological area of PLC. The most productive companies, in proposals and applied solutions, are DS2, OPERA, Panasonic and Home Plug [86]-[89].

In general the industrial standards are divided into those of early years and those of latest years, which in turn can be defined as low speed and high speed versions respectively.

1. Low Speed-PLC Early Years: The first standards developed were X-10, CE-Bus and LonWorks. As mentioned before, these were of low speeds but had of great acceptance since they were widely used and formed the basis for further standard development [90].

1.1 X-10: The first PLC standard, and though it had very low speed performance it gained wide acceptance. Basically its role focused on signal controlling over power lines to control electric devises like dimmer and light switches. Home control system set up needs no extra wiring [91].

1.2 CE-Bus: Now it is known as ANSI/EIA-600. Its development purpose is to provide a standard using the available wire medium exist in door for home automation. The need of standards with better performance results than the already existing X10, leaded the members of Electronic Industries Alliance (EIA) to develop the CE-Bus standard [90].

1.3 LonWorks Specification: This standard provides solutions for smart grid applications and home automation using narrowband modulation, performing low data rates in the range of 3 to 6 KBPS. The communication mediums supported are power lines and twisted pair. Its technology production started from Echelon Corporation. The later published and accepted, ANS/IEC 709-1, ANS/IEC 2, ISO/IEC 14908-1/-2/-3 and ISO/IEC 14908-4 standards are based on the LonWorks Specification [90], [92].

2. High Speed Later Tears-Today

Recent PLC technology research results promise better performance since already accepted solutions are taken into consideration from the area of wireless communications.

Even though wireless and PLC technologies have fundamental differences, due to the different communication medium, although similarities occur since the power line channel appears multipath behaviour and limitations, which are addressed almost the same as in the wireless communications task.

By implementing the solutions of wireless with the necessary modifications, PLC addresses many problems that faces and as a result better performance is already achievable.

In detail, consider the already published and accepted standards of HomePlug Alliance, DS2 and HD-PLC [88] as the latest progress in high speed standardization development.

HomePlug Powerline Alliance

HomePlug Powerline Alliance is a non-profit industry association formed by several industry leading companies and its scope is to create specifications for powerline networking products and services.

Already many specifications are acceptable standards for high speed powerline networking and used worldwide. Among them the most recognized are HomePlug 1, HomePlug AV, HomePlug BPL, HomePlug Command and Control [89].

2.7.2 Main Standardization Bodies

Worldwide main Standardization bodies for the areas of electronics and telecommunications are briefly presented as follows [79], [80].

2.7.2.1 International Bodies

Among the most significant international bodies in standardization on telecommunications and electronics consider: 1) the International Electro technical Commission (IEC), 2) the International Special Committee on Radio Interference (CISPR), 3) the International Organization for Standardization (ISO) and 4) the International Telecommunication Union (ITU) [78].

2.7.2.2 American Bodies

While among the major bodies in the United States that produce electronic and telecommunications related standards are: 1) the Federal Communications Commission (FCC), 2) the Institute of Electrical and Electronics Engineers (IEEE), 3) the American National Standards Institute (ANSI), 4) the Electronic Industries Alliance (EIA), 5) the Telecommunications Industry Association (TIA) and 6) the United Telecom Council (UTC) [78].

2.7.2.3 European Bodies

In Europe main bodies in standardization for the areas of electronics and telecommunications are: 1) the European Telecommunications Standards Institute

(ETSI), 2) the Comité Européen de Normalisation Electrotechnique (CENELEC), 3) the Information and Communications Technologies Standards Board (ICTSB), 4) the Office of Telecommunications (OFTEL), 5) the Radiocommunications Agency (RA), 6) the European Conference of Postal and Telecommunications Administrations (CEPT) and 7) the International Electro-Technical Commission (IEC) [78].

Chapter 3 "PLC Applications and Techniques"

3. Introduction

As it is presented in previous two chapters, PLC technology development goes forward real fast. Of course the expected economic-social benefits are driving this progress and that is the reason why it gains recently so much attention.

The truth is that despite the existing unsolved technical matters, while simultaneously waiting the forthcoming Standards, numerous PLC applications are already available for use. While simultaneously the number of the available and proposed PLC applications increases as the interest of PLC technology does so also.

Since the relevant area is quite complicated, PLC applications presentation is divided into the following three parts:

1. Indoor PLC applications which in turn are divided into those related to Smart Home Automation, Voice, Video and Multimedia. As it concerns Smart Home Automation applications these are well known for a long time ago since several industry proposals and products are widely available in the market place.

Because of the later further improvement of PLC systems performance, with the implementation of broadband techniques for narrowband PLC, additional more demanding applications are ready to take place.

The above mentioned additional PLC applications are Voice, Video and Multimedia. They came afterwards, in relation to simple home automation PLC applications, since their minimum requirements in order to work properly are relative to the available data rate and the implemented standard capabilities under which they are operating.

2. Outdoor PLC applications cover a quite extended area which includes Industry, Automotive, Specific, Smart Grid and PLC Broadband access applications.

In general, Industry PLC applications are mainly focused in controlling and managing industry related devices.

While, nowadays the automotive industry with PLC technology is finding an advantage of great significance to reduce car cabling costs, reduce cars weight for further fuel economy and to provide more advanced automation mechanisms.

As specific PLC applications consider those who do not belong to one of the above mentioned categories and in general are proposals for a specific theme.

The Smart Grid concept is of great significance due to the expected benefits. PLC technology is one of the main technologies that will be used in this concept. So PLC applications will be implemented in any case.

Finally PLC broadband access which is considered among the most promising PLC applications is briefly presented.

3. Hybrid PLC techniques are based in the combination form between wireless and PLC technology in order to benefit from the advantages these two technologies provide.

3.1 Indoor PLC Applications

3.1.1 Smart Home Automation

The in-home/building area is one of the fundamental application areas for PLC systems. Many different applications are available and almost all recent PLC development is based for in-home/building usage.

In general in-door applications are categorized into low and high data rate. The first are used for control and automation systems for in-home/building applications. These applications aim to control and manage all devices' operation that exist in a house/building and are connected to power lines. And those of high data rate provide networking solutions, which may be compared with those of wireless communications networks according to the latest available PLC performance results.

Starting from the first official available solutions like X10, Insteon, CEBus, PLCBUS and LONWorks, until the more recent and advanced HomePlug Command and Control, several systems and proposals for home automation are available [94]-[101].

Despite the differences between the existing systems, the final implementation decision is based on many personal and technical details. The truth is that in-home/building automation PLC based applications, have reached a quite acceptable level.

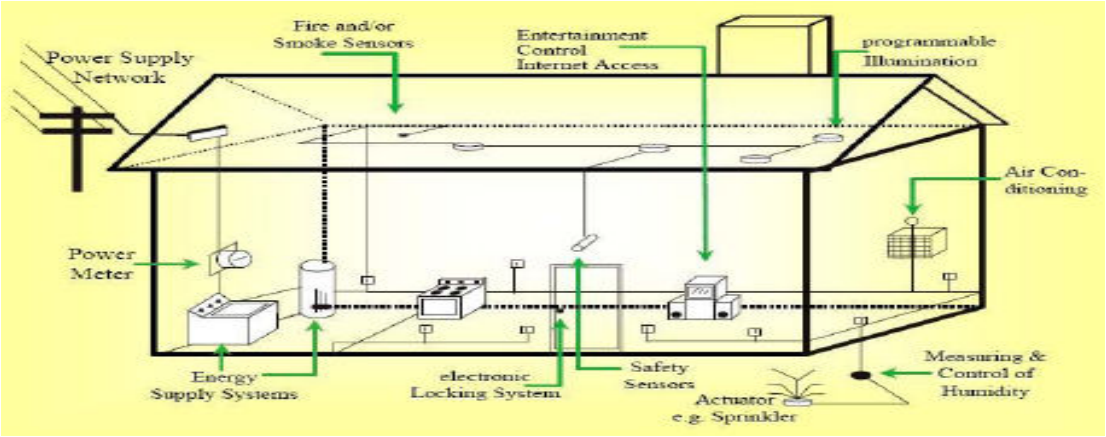

Figure 3.1: PLC based Smart Home Applications.

3.1.2 Voice, Video and Multimedia PLC applications

Voice, Video and Multimedia PLC applications in order to work properly, the available data rate and bandwidth must have high values so as to caver their demands. Nowadays as users' demands for multimedia and real time applications increase many attempts have already been made to satisfy the markets' need

Recently Home Plug Alliance developed some industry standards to support in home PLC applications towards this direction.

The first standard is the HomePlug AV whose scope is to support in home entertainment applications. It provides distribution of data and multi stream entertainment, including high definition TV and home theatre. It offers data rates of 200Mbps and it is considered as the best solution for this purpose compared to other available solutions.

Another standard, which is under development, is the HomePlug AV2 designed to face the needs of more advanced applications like IPTV, VOIP, multi- user gaming and home IT networks and it is expected to offer much greater data rates than those of HomePlug AV [102]-[105].

3.2 Outdoor PLC Applications

3.2.1 Industry PLC Applications

Even if PLC applications, in early PLC years, were predicted for use in industry, unfortunately recent PLC development showed little attention towards this area. Actually in relation with in-home PLC applications, very little work has been done.

The reason why this happened is that industry PLC applications need more advanced performance capabilities than those needed for in home, public or professional PLC based LANs.

On the other hand the industry is willing to reduce the extra wiring needed for controlling industry electric motors because of the significant additional cost. So the possibilities for industry to implement PLC applications increased, as today's PLC systems show acceptable performance.

Most industrial PLC applications are used for sensor networks, programmable controller connections, motor speed control, power system control-monitoring and for places where it is rather difficult or dangerous to place extra wiring [106]-[109].

Lately, efforts towards employing a HomePlug based protocol for industrial applications have been proposed [110].

3.2.2 Automotive PLC Applications

According to [111] during the last 50 years the essential wiring in motor vehicles from 4kgm in weight increased almost 2300%. This means that the total wiring weight reached up to 100kgm nowadays. This happened due to the advanced electronic equipment, devices and applications that are offered in synchronous motor vehicles. As it is estimated in [111], from the total cost of a motor vehicle, 3% comes from the wiring needs.

All this extra wiring leaded up to more expensive, heavier, complicated motor vehicles that consume more fuel and require more money to manufacture and maintain.

On the other hand the existing solutions for in vehicle communication like CAN, LIN and Flex-Ray, even if these provide high throughput, finally require extra wiring as the electronic devices increase [112].

As latest PLC systems show improved performance capabilities and manufacturers had to face the above mentioned problems, the idea to use PLC technology in the automotive area was raised. Motor vehicle manufacturers count on the benefits that PLC technology provides as it needs no further wiring to provide advanced automation control and communication operations. Until today many

attempts have been made to finally implement PLC applications in motor vehicles [115], despite the problems that occur [113].

Indicative PLC applications for motor vehicles are proposed for hybrid in-vehicle video help system for car parking [117], for communication between the truck and its trailer [118] and for controlling Truck and Trailer Backlights [119].

Recently, attempts based on indoor PLC standards like HomePlug PHY Layer 1.0, HomePlug AV and High Definition Power Line Communication - HD-PLC for motor vehicles applications has taken place [112], [114].

3.2.2.1 Special Automotive PLC Applications

The expected benefits of PLC systems into the automotive area moved researchers' interest for additional further implementation of these systems into almost all kind of vehicles that exist, including ships, aircrafts, train and satellite.

3.2.2.1.1 Ship

Several communication techniques such as wireless, fiber and Ethernet are used in ships for automation system controlling and in ship communication. But due to the additional weight of the wiring needed, for Ethernet or fiber, to cover the long in ship distances, which increases the overall cost and the limitation use of wireless systems in ship, a solution had to be found [120], [121].

Attempts [122]-[124] towards the implementation of PLC technology over ship low voltage power lines showed that it is possible to transmit communication signals in an effective way.

In [125] the Shipboard Power System with the implementation of broadband PLC technology is considered as the next in ship communication network.

3.2.2.1.2 Aircraft

The interest for PLC applications over aircraft power lines is placed in the late 90's, according to [126]. In 1999, in UK, a study for the influence in aircraft systems from broadband PLC [127] seems to be the first effort towards that specific area. Since then, quite much progress has been made and especially for PLC related applications.

Indicative application proposals for PLC technology implementation over military aircraft power lines with the expectation to reduce the wring weight in the aircraft instrumentation system were proposed in [127], [128].

While proposals for civil aircrafts include PLC based applications for mobile communication and internet access systems availability to the passengers during the flight and for the cabin lighting system in [129]-[132].

3.2.2.1.3 Train

According to the latest trends among the Train Operator Companies for increased passenger satisfaction, several additional PLC applications are added in order to provide audio, data and video information. A flexible and cost effective PLC based Train Passenger Information System is proposed for this purpose in [133].

3.2.2.1.4 Satellite

Researcher's interest for further PLC application implementation leaded to satellites. Since all kind of vehicles have a power distribution network, an idea is to reuse the existing wiring used for power. The application proposal is for a PLC based back up LAN into a Space Shuttle [134].

3.2.3 Specific PLC Applications

Numerous proposals have been made for further PLC applications development. In many cases it is not so clear into which application category these proposals should fit best. For example, special PLC systems [122] are positioned the airfield lighting control and ship power distribution network. So, in order to overcome this rather confusing situation some extra proposals for PLC applications are presented in this part which is called specific PLC applications.

3.2.3.1 Street lighting control

Several implementations and proposals have been made in order to control outdoor lighting systems with the use of PLC technology [135], [136]. According to [136] it is clear that solutions for more advanced lighting operation capabilities are

available and several countries have already taken the risk-opportunity to implement these solutions in their street lighting control systems.

The fact is that street lighting control and management leads into a further improved lighting system for better public safety, reduced energy consumption, reduced air pollution and minimum operation cost.

Referring to the latter, it is calculated that street lighting requires almost the 40% of a city's electricity needs [135]. As it shown in table B9, the annual estimated electricity cost and CO2 emissions due to the street lighting system in several different countries are really high.

On the other hand in Norway where the most advanced intelligent street lighting system in the world is being implemented, they managed to reduce their electricity consumption by about 30% [136].

This system is based on electronic dimming gear and power-line communication applications. The overall performance of the system finally managed to increase the public safety level while the energy consumption was reduced.

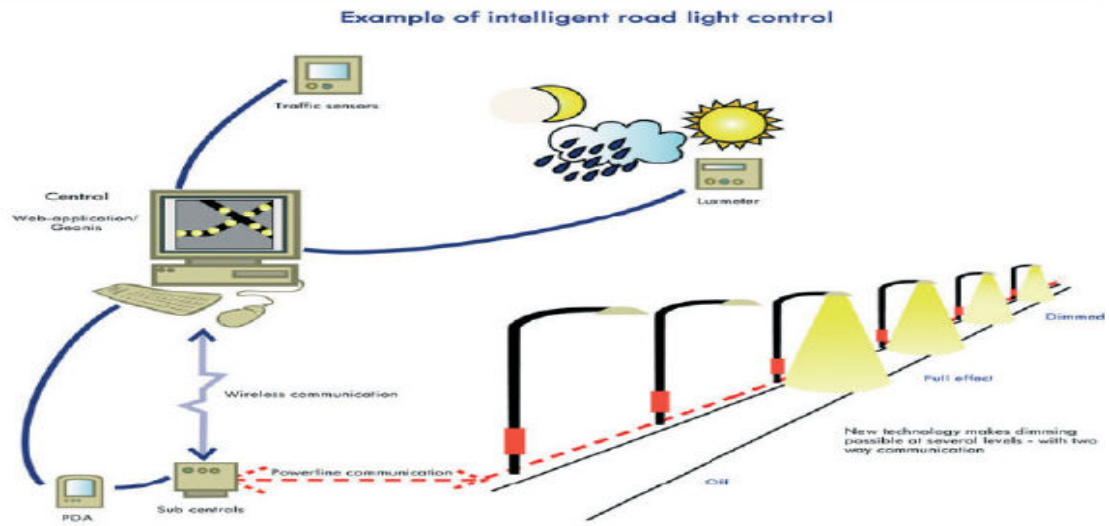

Figure 3.2: PLC based Street lighting control

3.2.3.2 Airfield ground lighting control

Airfield Ground Lighting systems have many serious responsibilities and affect into the overall safety operation of an airport. In general these systems are driving the aircrafts by providing them with visual reference and additionally they provide safe

air traffic control. Also responsibilities during the progresses of aircraft approaching, landing and taking off are based on AGL systems.

The existing AGL systems follow the security restrictions by the Federal Aviation Authority and the International Civil Aviation Organization recommendations. According to them the wireless technology solutions are not accepted for AGL systems, due to the fear of causing interfere with the radio navigation systems.

Due to the above mentioned and as these systems need further development, according to the airport safety regulations, PLC systems showed up to be the best available solution for AGL systems development. Proposals for AGL systems using PLC technology are already available [137], [138].

3.2.3.3 PLC over Direct Current

Almost all work that has been done in the area of PLC over DC is mainly focused on the automotive field, since vehicles power electric network is based on DC.

In recent years further work for PLC over DC is presented in [139] - [142]. For the first case, PLC technology is used in the area of wearable computing systems and especially in wearable health monitoring, which is one application of these systems. While several PLC applications for the areas of health care, home automation and material handling are proposed.

3.2.3.4 Various PLC Applications

Additional PLC applications for multiple uses include:

1. Fire security system for in-home installation [143], which works through power lines and it can be used and as an in home alarm system controlling. It works by warning in case of fire and sending alarm signals through power lines.
2. Another PLC application is proposed in [144] and is used for detecting illegal electricity usage. This system works by comparing values of the energy used with the use of a detection system.
3. A measuring system for high temperature applications where the data transmission is based on point to point PLC to the corresponding control unit is proposed in [145].

4. Tele-surveillance PLC based systems for several indoor and outdoor applications scenarios are available according to [146].

5. Of great significance PLC applications may also be used in the e-health domain [147].

6. Additionally PLC applications may also be found in Microprocessors [148]-[151] and visible light communications [152]-[155].

7. PLC applications may also be used as emergency communications [156].

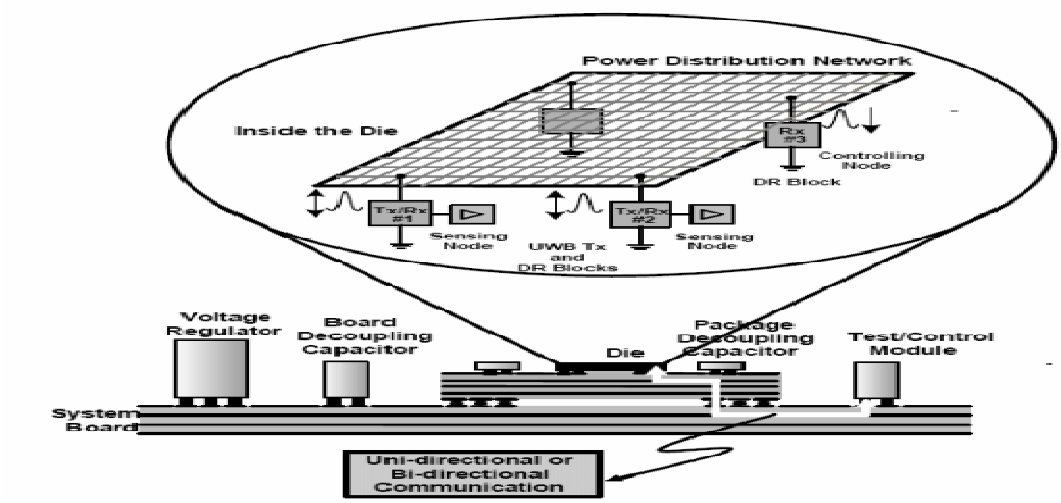

Figure 3.3: PLC in microprocessor environment.

3.3 Smart Grid

3.3.1 Smart Grid Fundamentals

Nowadays, taking into consideration the existing electrical energy worldwide demands and the forecasting energy consumption needs, according to the International Energy Agency [157] and the American Energy Information Administration [158], there will be an increase of about 2% per year until 2030 [159]. Which means that the energy consumption needs during the next 35 years will be doubled. Since there is no doubt over this prediction and as long as the existing power network suffers from several technical matters like transmission loss and the energy consumption is 80% based on fossil fuels a solution has to be implemented immediately [159].

In order to face, manage and overcome the above mentioned predictions European Union [160] and United States societies and economies, despite their own

vision differences [161], either each one alone or together as the Atlantic Council of the United States and the U.S. Department of Commerce proposed [162] to work in coordination, look towards a more advanced electricity power network that could manage and deliver the energy concept in a much more effective way. The solution is expected to be given with the Smart Grid concept.

Taking the opportunity of PLC technology's recent development, an idea came up to use this technology into the Smart Grid concept whose aim is to substitute the existing old electricity power network [163]-[165].

The meaning and hopeful capabilities of the Smart Grid concept can be understood by its definition and even if there is no official definition several attempt ions have been made. So according to the European Technology Platform "Smart Grids are defined as electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies." [166] Another available definition is given by IEEE which says that "Smart Grid is the modernization and optimization of the power grid so that is more reliable, efficient, secure and environmentally neutral."

In a few words the smart grid concept focus into a network implementation of technologies that contribute to further improved energy transmission and distribution, provide customer interaction with the power grid and provide advanced operation capabilities for the power grid.

Finally, despite the fact that Smart Grid development is crucial matter for all nations and even if most of the technologies that are needed for the grid improvement are available, however there are numerous barriers that influence negatively further investments. In general these barriers are divided into industrial and technical, regulatory and social-economic [167], [168].

3.3.2 Smart Grid Benefits

The expected Smart Grid benefits can be divided into:

1. **Consumer Benefits:** With the implementation of smart meters, consumers have the ability to use electricity as much they need and when they need it, to manage and

control their consumption and to know how much they pay each time. Additional options may also be provided.

2. **Environmental Benefits:** Due to the advanced control and management of the energy consumption, less gas emissions will be produced. Additionally by controlling and programming the operation hours of smart devices when there is low electricity demand it improves grid operation.

3. **Workforce Benefits:** As governments and industry utilities invest on this concept, many related area workers will benefit since new working opportunities will be available.

4. **National Security Benefits:** A better organized and prepared smart electric power system will have the capability to provide more advanced electricity recovery mechanisms against emergencies like extreme weather conditions and terrorist attacks. So blackouts, due to whatever reasons they happen, can be handled better since the available electricity will support emergency services at first and provide a better effective electricity recovery.

5. **Electric Power System Benefits:** Since these new smart technologies will be implemented into the electric power system the expected benefits will positively affect its performance in: more efficient electricity transmission, cost reduction for controlling, management and operation, more effective electricity restoration and security [169]-[172].

3.3.3 Smart Grid Priorities and Driving Technologies

The essential priorities for Smart Grid standards development as they have been identified by NIST Framework and Roadmap for Smart Grid Interoperability Standards are energy transport and storage, network communications and cyber security, advanced metering capabilities and management of the distribution grid [173]-[174].

Among the high priority areas which are also been identified consider interoperability, cyber security and standardization [175].

Accordingly the U.S Department of Energy in order to succeed into the Smart Grid final aim identifies five fundamental technology areas that will drive this development, which areas are considered the: ***1.*** *Integrated communications,* ***2.***

Sensing and measurement, ***3.*** *Advanced components,* ***4.*** *Advanced control methods and* ***5.*** *Improved interfaces and decision support* [176] - [180].

Within these areas numerous technologies are contained, while some of them are already developed and some others are under development. The prediction is that many different areas will be influenced positively by the changes that the Smart Grid will bring.

3.3.4 Smart Grid Standards

Current status of Smart Grid standardization development is contained in Appendix A where are presented all approved and under development standards according to IEEE, NIST and IEC [181] - [185].

Recent efforts to overcome the crucial matter of smart grid interoperability are relying on the IEEE P2030 Standard which full name is "Draft Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads" and it is still under development [186].

3.4 PLC Broadband Access

Among the most significant PLC applications is broadband internet access. In this case, it is known as broadband over power lines, BPL, and may offer last mile broadband internet access through medium or low voltage power lines. [Figures 3.4-3.5]

Despite the fact that there are already acceptable and well-known solutions like DSL and cable lines that offer broadband internet services, the benefits of using the existing power lines on behalf of PLC, gives the right to be considered as the third wired solution. Additionally the fact that electric power lines are running almost everywhere including and rural areas makes broadband PLC stronger in the market place.

In general it is called access BPL when referring to the part over medium/low voltage power lines or in-house BPL when referring to the in-home power lines respectively.

Basically there are two ways to connect with BPL, end to end or hybrid. The first is when only power lines are used and the second is combination of power lines and another technology like wireless or by passing through the transformer or bypassing the transformer [187],[188].

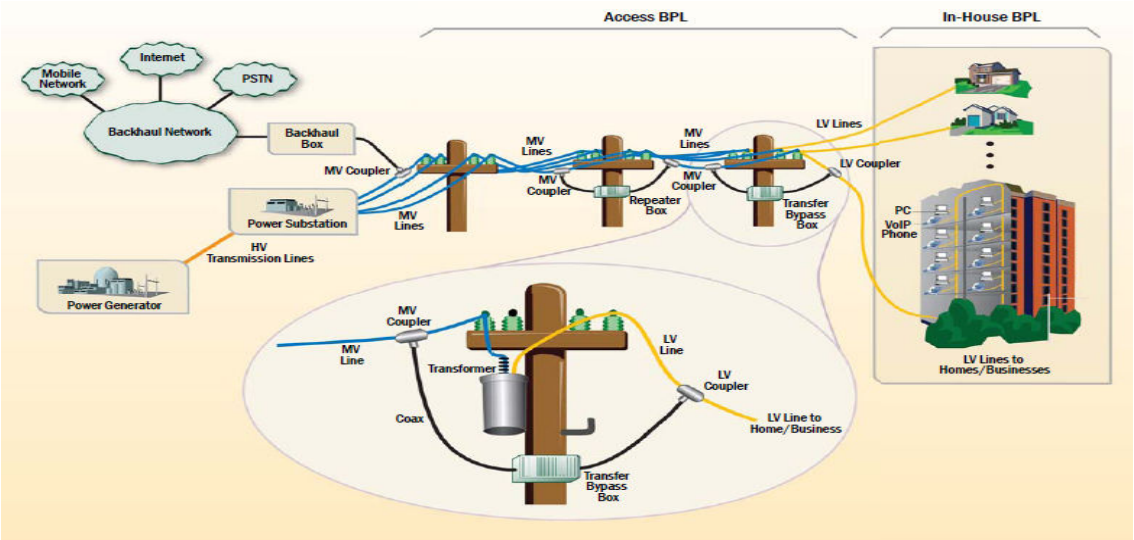

Figure 3.4: Broadband PLC Types

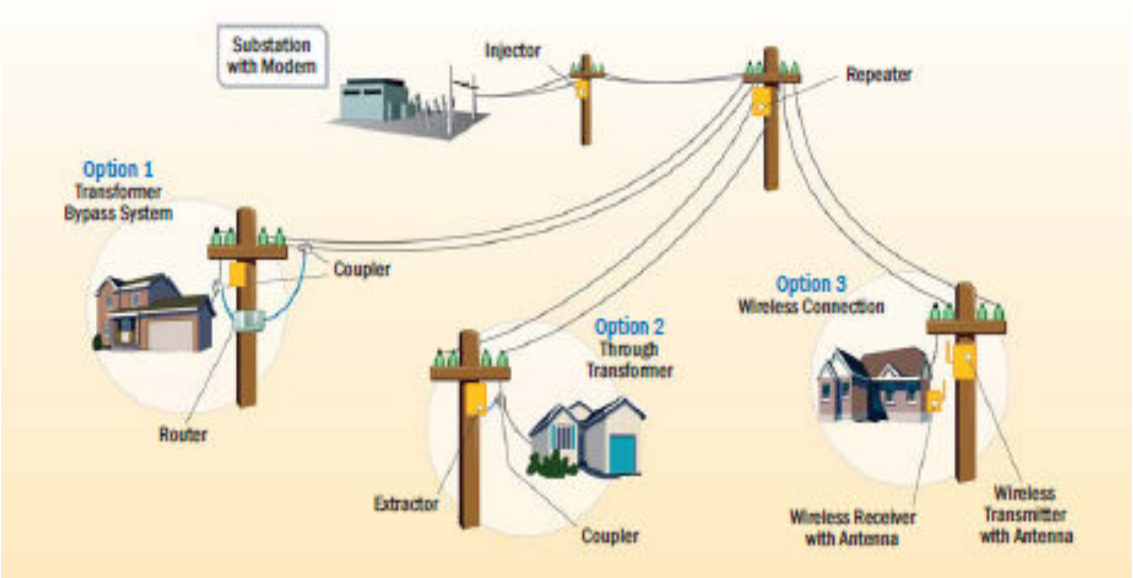

Figure 3.5: Broadband PLC connections

3.5 Hybrid PLC Techniques

Recent development activities in the area of communications systems lead to today's available data communications technologies. Whether these are operating over wire lines or not, these are designed to serve the communication task under certain conditions. The fact is that several times, depending on the specific

circumstances, it is more effective and economically accepted to use a combination of these technologies in order to extend the existing communication system capabilities over a greater coverage area.

The idea is to make the best use of the existing technologies and have a successful coexistence without causing extra interference. Of all available combinations the one between power lines and wireless is the first choice since there are no additional problems as their operation frequencies are different and both technologies work properly [2], [189].

These techniques are called Hybrid PLC and provide the ability to extend to coverage area of a power line communication system by a factor which is related to the wireless communication system coverage area. Many available combinations of these techniques exist since they can be used either for extracting the PLC signal from the MV power line into a wireless channel or for injecting the wireless signal into the LV power line and distribute over all in-house wiring [190], [191].

3.5.1 Hybrid PLC Applications

Representative Hybrid PLC applications for four different situations are:

1. Outdoor HPLC: A smart application is proposed in [192] for low cost WAN implementation using the outdoor lighting system by using a node on every PLC connected lamp.

2. Indoor HPLC: Another HPLC application of great significance [193] is used for building energy and automation management where there are indoor radio limitations of the wide usage of wireless sensors.

3. HPLC in Vehicles: In [194] a car parking assistant is proposed which works with the usage of PLC connected cameras that work with wireless transmission of the signal to the driver.

4. HPLC and e-Health: E-health applications and medical data exchange for hospital environment, are proposed in [195] through a hybrid PLC network.

Chapter 4 "Market Global Trends"

4. Introduction

The aim of the last chapter is to present PLC technology market global position and its future perspective, in relation with competitive broadband technologies and current social-economic status. In order to do so this chapter is divided into three parts.

The first part is focused on PLC trials global development. The truth is that despite the fact that there are numerous PLC trials around the world, some of them stopped their operations while others just started, for reasons that are about to be explained.

Even if PLC technology gains ground nowadays it is not enough to guaranty for its successful market acceptance and deployment, so basic factors influencing PLC development and basic PLC competitive broadband technologies are taking into consideration.

The second part is referred to information and communication technologies, ICT's, impact and current global statistics related to competitive to PLC broadband technologies. Additionally, basic current social-economic matters, like economic crisis and climate change, are taken into consideration in relation with ICT's and how they influence each other.

Finally, after taking into consideration all the above mentioned, comments and conclusions are kept for the third part of this chapter.

4.1 PLC Global Market Development

As it is expected it is not so easy to have a clear over view of all PLC systems that have been implemented around the world. So in order for this presentation it is more convenient to make use of the OPERA Worldwide Market Research Report [196].

According to this report several attempts to implement PLC systems have already taken place worldwide.

At first Europe area is observed, which in turn is divided into Western and Eastern Europe. For the Western Europe case, PLC systems are well situated and are

mostly moving toward Smart Grid and in-home applications. Where as an alternative last mile connection, at this time, PLC have left behind compared to other competitive broadband technologies like DSL and wireless.

While, in Eastern Europe PLC systems do not go so well, either due to the destroyed, by the war, electro-communications infrastructures or due to the competitive, to PLC, alternative broadband technologies like fixed and mobile. The probability to improve PLC deployment in these countries is with the electrical grid infrastructure reconstruction.

Asia, in turn, is one of the most significant areas for PLC systems development and especially the areas of Japan, China and Korea. In particular, Smart Grid and in-home applications are already in use. While hybrid PLC/FTTH systems, for broadband access, are used for in-home LANs.

In USA, PLC development has gained ground both in standardization contribution and further PLC systems implementation. In general, PLC applications are used in numerous ways, either for home networking or as broadband access solution. Also Smart Grid development and applications are strongly supported by the U.S nations.

Many PLC systems, for in-home and broadband access, are been implemented in South America, especially in Brazil and Argentina. While in these countries their electricity infrastructures are prepared to benefit from Smart Grid applications.

Australia, shows interested in PLC systems since many PLC trials are already been implemented and work under pilot status, till all technical and emission problems will be solved.

For the case of Africa little PLC development has taken place, mostly in South Africa, since there is limited electric network infrastructure coverage within all Africa area. So taking the opportunity, alternative telecommunication providers, mostly mobile and wireless, have already advanced development within last years. [196]

4.1.1 Broadband PLC Trials

The truth is that numerous broadband PLC trials have been implemented, either for commercial use or under supervision, in many countries.[198]-[204] Despite the

technical problems that existed, the interest for these systems during years 2000-2004 was great. The predictions, for further deployment, were quite positive while the trials number increased.

Unfortunately, and against the predictions, several different reasons leaded to trials drawback round in year 2006 and later. Among the most serious reasons are interference, lack of standardization, competition with alternative broadband technologies, limited interest for the technology and difficulties in commercial deployment.

Recent progress in the standardization area, and as severe technical problems are about to be solved soon, influence positive and the interest for PLC systems increased again. So, the paradox that appeared is while old trials either continue or stop their operations, simultaneously new trials are starting their operation while others are about to soon.

4.2 Factors Influencing PLC Development

Despite the fact that PLC technology is gaining ground nowadays and even if it provides numerous indoor, outdoor applications and broadband access solution, as it concerns its deployment it faces serious challenges.

These challenges are divided into three basic categories which in turn are: technological, social-economic and regulatory [53], [197].

4.2.1 Technological Challenges

The most serious technical matters responsible for the slow deployment of broadband PLC systems are frequency interference, noise, signal attenuation, interoperability, security, low performance and lack of standardization.

The fact is that during recent last years with the implementation of techniques used in the wireless communications area, the performance of PLC systems improved and challenges like noise and interference minimized quite a lot.

On the other hand according to the recent PLC standardization status, the existing standards and those forthcoming, it is expected that will solve most challenges that PLC faces.

4.2.2 Social- Economic Challenges

Broadband PLC systems face difficulties as it concerns their commercial development. The difficulties that occurred are related to the economic model under which these systems should be developed.

The problem is under which conditions energy-electric companies could offer broadband PLC services. Since these companies have an extra advantage as energy providers, they can use the electric power network for free, against competitive broadband suppliers. Another matter is what would be the impact into the electric service quality if these energy-electric companies offer Broadband PLC services.

Additionally energy-electric companies could easily provide broadband services in rural and remote areas as the electric power network reaches almost everywhere. This of course is another benefit for these companies but it is against the rules under which communication providers' work [197].

4.2.3 Regulatory Challenges

Another challenge is the regulatory status under which broadband PLC suppliers could work. The truth is that only cooperation between electricity and communication regulation authorities can lead to the solution. The question remains why energy-electric companies cannot offer broadband services and enter the communication market.

As governments relay on the broadband deployment and smart grid development is strongly supported, it is matter of time for the regulation authorities to set the market rules [197].

4.3 PLC Competitive Broadband Technologies

The competitive broadband access technologies are divided into fixed line and wireless. Referring to fixed line consider the x-DSL, FTTH, FTTC, cable modem and PLC. And for wireless technologies consider satellite and mobile.

In general, it can be said that there is no perfect solution for getting broadband access. Depending on the particular circumstances like location, money availability and users' needs, there are several different ways to provide broadband access by using one or more of the above mentioned technologies.

The truth is that these technologies, despite their technical and performance differences, Appendix B [1]-[3], are all considered competitive to PLC. In order to understand PLC potentials into the broadband access technologies market, PLC systems are compared with currently most used technologies in the area.

Starting from the fixed line technologies, fiber, FTTH-FTTC, is considered as the most effective and expensive solution. But even if it has tremendous potentials and performance results its deployment is related to the high cost needs for improving the fiber network infrastructure.

Accordingly, the cable modem solution is mostly used within big cities where the essential network is available. In general it is not suitable for rural and remote areas, since there is no cable network coverage. Even though, it managed to cover the 29% of fixed broadband subscriptions in the OECD countries in 2010.

As it concerns the x-DSL solutions, just take into consideration their 58% coverage in 2010, table 4.1, as a proof of their spread deployment. In general these technologies are using the existing telephone network infrastructure which is considered among the biggest that exist. Their advantage is the low cost installation as it needs only a modem. Despite their performance results are related to the distance between the station and the end user, though they can offer satisfying broadband access services at low cost.

For the case of the wireless technologies, the satellite broadband access choice is mostly used for connecting rural and remote areas. It deployment though faces the implementation and service costs that are much higher than all available wired and wireless solutions. Its basic drawbacks are, the limited connection speed, compared to x-DSL and Cable Modem solutions, and the long delays due to the distance between the satellite and the dish receiver.

Finally, taking into consideration that recent mobile cellular development counts over 5.3 billion mobile subscriptions globally, with 80% coverage in rural areas and 90% global population availability. While mobile broadband subscriptions did better than fixed broadband subscriptions in 2008 reaching up 73% coverage in OECD countries in 2010, consider mobile broadband access technology among the strongest players in the market place [196], [205]-[208].

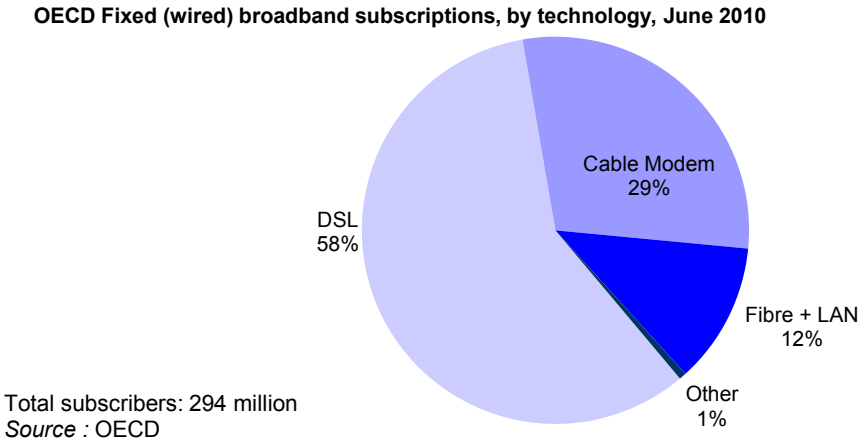

Table 4.1: OECD Fixed broadband subscriptions, by technology, 2010

4.4 Information and Communication Technology Global Market Overview

4.4.1 Information and Communication Technology Impact

Recent ICTs' development showed their importance into almost all human activities. Their contribution into the economic growth and development started to be observed at the end of 1990's, as a result of their positive effect into productivity and gross domestic product [16], Table B5.

After that, it is recognized that the impact of ICTs influences almost all areas of peoples' lives. In brief these areas are human and social-economic, research and development, environment, productivity and national development [16].

Recent crisis in the areas of Egypt and Japan, despite their origin differences, verify how ICT's may impact into human and social matters. For the Egypt case, ICT's were used for preparing the authoritarian regimes instability and for the Japan case, after the tsunami took place, ICT's were used from the survivors to find their family members or friends whether they were alive or not.

Nowadays, their development is such of great significance for all people, that leaded the World Summit on the Information Society (WSIS) to set a ten target ICT based programme. These targets are [209]:

1. *To connect villages with ICTs and establish community access points*

2. *To connect universities, colleges, secondary schools and primary schools with ICTs*

3. *To connect scientific and research centres with ICTs*

4. *To connect public libraries, cultural centres, museums, post offices and archives with ICTs*

5. *To connect health centres and hospitals with ICTs*

6. *To connect all local and central government departments and establish websites and e-mail addresses*

7. *To adapt all primary and secondary school curricula to meet the challenges of the information society, taking into account national circumstances*

8. *To ensure that all of the world's population have access to television and radio services*

9. *To encourage the development of content and put in place technical conditions in order to facilitate the presence and use of all world languages on the Internet*

10. *To ensure that more than half the world's inhabitants have access to ICTs within their reach.*

4.4.2 Economy and ICT

Starting with current economic crisis impact on ICT industry, the ICT sector is expected to be influenced almost the same as did during previous crises. In general ICT companies with steady cash flow are expected to benefit in relation to their competitors. Additionally new business opportunities are created and new technologies are expected to enter. In general, the expectation is that ICTs will overpass this crisis as peoples' communication needs increase [214].

As it concerns ICTs contribution in recovering from the crisis, ICTs' impacts are expected to drive forwards growth and help for economic recovery. ICTs' contribution into productivity growth, employment, education, health and public services is recognized and that is the reason why OECD countries and governments turn their attentions into ICTs development [215], [216].

More precisely, in developed and emerging countries governments focus on broadband and telecommunication services extent ions to rural and un-served or under -served areas. While governments in developing countries focus on developing sectors like health, education and housing, where is more needed.

Almost all governments, in developed and developing countries, depending on their current ICT development, have in priority at least one of the top ICT policies

for their economic recovery. Basically these ICT policies include ICT skills and employment, broadband access services, R&D programmes, venture finance and ICTs impact on the climate change [216].

4.4.3 Climate Change and ICT

According to [214]-[217] the ICT sector is closely connected with the climate change in three different ways.

Firstly, with no doubt the ICT sector is partly responsible for the global warming since its contribution to the global total greenhouse gases (GHG) emissions is around 2, 5 % [214].

User's devices, mainly internet-mobile equipment, demands in energy and the heat they radiate are basically responsible for the above mentioned calculation. To make it more clear, take into consideration that internet users and mobile subscriptions increased dramatically during last decade, as shown in table 4.2.

Secondly, the ICT sector is negative influenced by the extreme weather conditions whose appearance increased dramatically during last years as a result of the global warming. And especially the sectors of telecommunications, transport and energy are suffering the most of these conditions.

And thirdly, ICTs are expected to dynamically contribute to climate change reduction [220]. Already, many organizations have taken the initiative in studying how ICTs may contribute in minimizing the effects that increase the climate change.[218]-[221]. More precisely, the idea is to combine traditional ICT with "green ICT" under certain environmental policies support.

According to OECD [220] the first thing ICTs should do is to minimize their greenhouse gases (GHG) emissions in order to reduce their direct negative impact into the climate change progress. And on the consumer's side, ICTs users should be more energy consumption sensitive. Additionally green growth and smart applications that could reduce energy use and material consumption will also be driven by ICT applications.

4.4.4 Information and Communication Technology Global Development

During the last decade, ICT global development had a significant and steady increase for the sectors of mobile subscriptions, internet users, mobile broadband and fixed broadband subscriptions. Almost all sectors were positively influenced except that of fixed telephone lines as they remained almost on the same levels until 2005 and then suffered a small decline, table 4.2

As a result Internet users development raised quite a lot, since it started from round 370 million users, round 7% of world population, and finally reached 1966 million users, which means 444,8% growth and 28,7% of the world population are internet users [212].

By level Internet users development shows that developing countries despite they reached 21,1% are still far behind from the 71,6% of the developed countries. Europe, Americas and CIS are driving the development, by region, with 65%, 55% and 46% respectively, while Arab States are close to the world average with 24,9%, with Asia-Pacific following closely with 21,9% and finally Africa which is far behind from all countries with 9,6%.

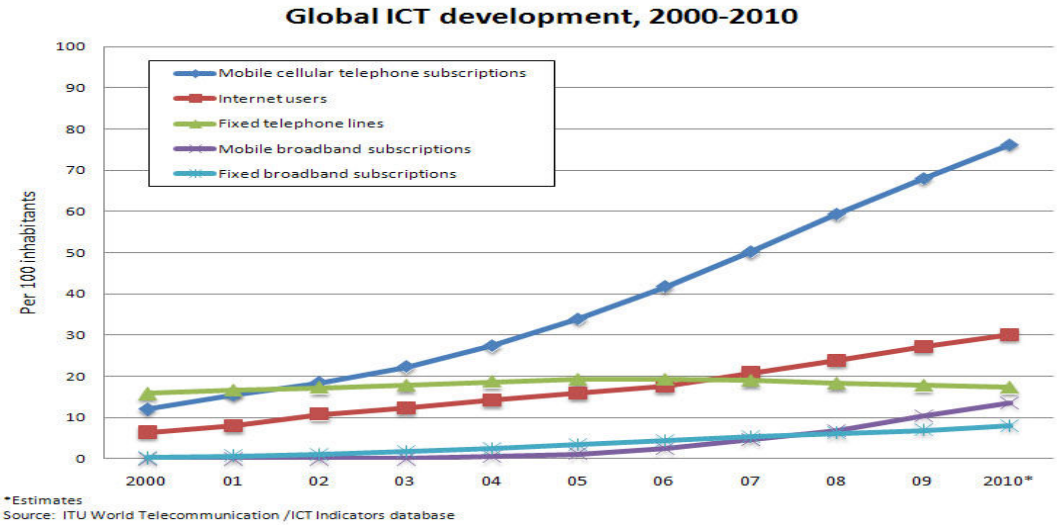

Table 4.2: Global ICT Development, 2000-2010 [211]

During the same period mobile broadband subscriptions development increased more compared to fixed broadband subscriptions as they finally count 12% and 8% respectively.

More precisely, fixed broadband subscriptions development, increased the world average to 8%, while developed and developing countries reached 24,6% and 4,4% respectively.

Additionally by region development shows that Europe is leading with 23,9% following by Americas with 15,5%. Bellow world average are standing Asia-Pacific and Arab States regions, while Africa once again stands far behind with 0,2%.

As it concerns mobile broadband subscriptions, the world average by level development reached 13,6%, while the difference between developed and developing countries counts 45,7% as they get 51,1% and 5,4% respectively.

While by region development shows once again Europe ahead with 46,3%, while CIS and Americas are following with 25,9% and 24,2% and once again Africa standing alone as finally reaches hardly 3,6%. Finally mobile cellular telephone subscriptions global development made the difference as they started from 12% and increased reaching up round 76%. It is worth mentioned the fact that by level development changed towards developing countries which finally reached almost 75%, while developed countries count the rest 25% [211].

4.4.5 Information and Communication Technology in Rural Areas

Taking into consideration that almost half of the world population is considered rural no matter if they are coming from developed or developing countries and localities global number is estimated that it passes the 3 million, their availability over basic ICTs sectors is examined in order to present current ICT development in these areas, table B6.

Global localities availability condition, for the sector of electricity is estimated above 57% in all regions except for Sub-Saharan Africa that reaches only 14%.

Accordingly, as it concerns telephone services availability it fluctuates from 38% to 51% for all regions, while Sub-Saharan Africa reaches only 12%.

Finally internet service availability is estimated with a 22% for Europe and Central Asia and 13% for East Asia and Pacific, followed by 7% for South Asia. While for the regions of Latin America, Caribbean, Middle East and North Africa the estimation is 3% and only 1,4% for Sub-Saharan Africa, table 4.3.

The estimation for the average availability, in developing countries rural households by regional division, for the sectors of electricity, radio, television, fixed telephone line, mobile, PC and Internet is taking into consideration, table 4.4.

Starting with electricity availability, more than 61% of rural households have electricity connection, except for Sub-Saharan Africa where only one in ten rural households have electricity connection.

Accordingly radio and television availability is above 50% for all regions, except for Sub-Saharan Africa with 6% and 51% television and radio availability respectively.

While as it concerns fixed telephone line except Europe-Central Asia and Middle East-North Africa that have 46% and 37% availability respectively, for all other regions the estimation is between 10% and 13% availability. Sub-Saharan Africa stands behind with 1% availability.

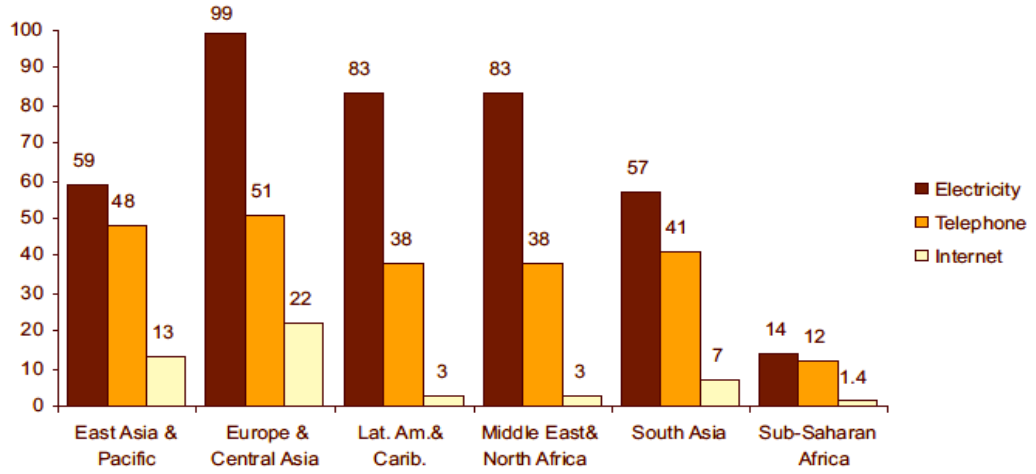

Table 4.3: Percentage of localities with electricity, telephone and Internet, by region [221]

With a 64% mobile availability Europe and Central Asia stand far from round 25% availability for all other regions. And again Sub-Saharan Africa stands behind with only 5% mobile availability.

Finally, computer and internet availability, except for Europe and Central Asia that reach 17% and 20% respectively, for all other regions is below 5%.

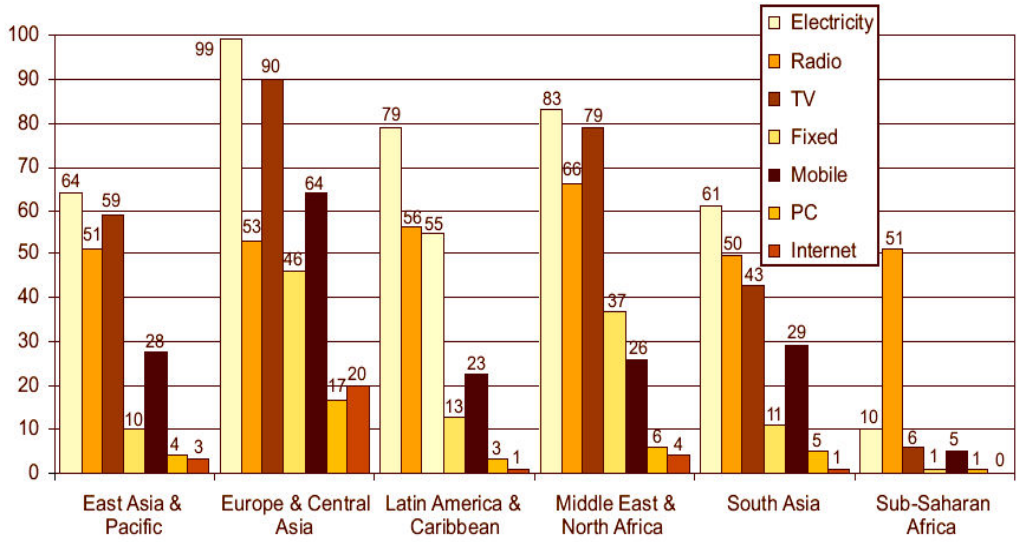

Table 4.4: Percentage of rural households with ICTs, by region [221]

4.4.6 ICT Global Development Conclusions

The estimation for global ICTs home availability in 2009 showed that over a quarter of world's global population had computer access at home, while almost one third of global households have a computer [208].

While in year 2010, as it concerns global households availability, in developing countries, for the sectors of internet access, television and computer, the estimation show 15,8%, 72,4% and 22,5%, while for developed countries the availability reach 65,6%, 98% and 71% respectively [207], [213].

Taking into consideration all the above mentioned concerned to ICTs' development and availability, the overall statistics estimation show that despite developed countries and in-city surroundings are standing at acceptable ICT levels, when referred to developing countries their performance is still far from the world average.

Additionally rural and remote areas suffer the most no matter if these areas are in developed or developing countries.

And despite the fact that mobile and cellular subscriptions had a significant rise during last years that is not enough to cover the ICT availability gap that exists.

4.5 Conclusions

Nowadays PLC systems are becoming more popular than ever. Their unique advantage of providing all these applications mentioned in chapter 3, over the electric power network without extra wiring needs and low cost implementation, make PLC systems a very promising competitor in the telecommunication market.

Even if the already successful x-DLS and mobile broadband technologies share the most of all global broadband subscriptions, this does not guaranty that PLC systems will fail. This assumption is based on four basic reasons: **1)** the network coverage over which PLC systems are operating, **2)** recent PLC standardization development, **3)** ICTs current development and **4)** global rural and remote areas population ICT needs.

The global electrical power network is the most extended network that exists. It reaches almost everywhere and its coverage is estimated as three times greater compared to the telephone line network. And as almost half of the world's population is considered rural, which in turn means limited ICT development, this provides to PLC systems the opportunity of having the biggest potential customer number that exists, compared to all other competitive technologies.

Additionally, basic technological challenges, that kept PLC systems development behind, are expected to be solved soon, as recent standardization development verify so. The already approved IEEE P1675 and the forthcoming IEEE 1901-1775 standards are expected to take off PLC systems development.

And since ICTs' development is considered necessary for: **1)** their beneficial impacts, **2)** recovering from current economy crisis and **3)** the climate change reduction, the possibilities of using PLC based applications for broadband, indoor and outdoor services, are greater than ever before.

Finally, taking into consideration all mentioned within this thesis, PLC systems are expected to play critical role into tomorrow's telecommunications market. The only thing that left in uncertainty is when and how the regulation challenges will be solved.

Comments

Due to the limited literature that exist for powerline communications, this thesis is based mostly on academic papers, journal articles, tutorials, technical magazines, conferences keynotes and reliable web sites.

The available literature till now counts six published books, which were all taken into consideration for writing this thesis. These books are:

1. Klaus Dostert, *"Powerline Communications"*, 2001, Prentice Hall PTR, ISBN 0-13-029342-3

2. H. Hrasnica, A. Haidine and R. Lehnert, *"Broadband Powerline Communications Networks"*, 2004 John Wiley & Sons, Ltd ISBN: 0-470-85741-2

3. Xavier Carcelle, *"Power Line Communications In Practice"*, 2006, Artech House, ISBN: 1-59693-335-6

4. Gilbert Held, *"Understanding Broadband over Power Line"*, 2006, Auerbach Publications, ISBN 0-8493-9846-0

5. Hendrik C. Ferreira, Lutz Lampe, John Newbury and Theo G. Swart, *"Power Line Communications Theory and Applications for Narrowband and Broadband Communications over Power Lines"*, 2010, John Wiley & Sons Ltd, ISBN 978-0-470-74030-9

6. J. Anatory, N. Theethayi, *"Broadband Power-Line Communication Systems Theory and Applications"*, 2010, WIT Press, ISBN: 978-1-84564-416-1

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Appendix A

A1. Approved IEEE Smart Grid Standards

http://smartgrid.ieee.org/standards/approved-ieee-smartgrid-standards, [03-03-2011]

1547-2003 IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

1547.1-2005 Application Guide for IEEE Standard 1547, Interconnecting Distributed Resources with Electric Power Systems

1547.3-2007 Guide For Monitoring, Information Exchange, and Control of Distributed Resources Interconnected With Electric Power Systems

1159.3-2003 IEEE Recommended Practice for the Transfer of Power Quality Data

802-2001 IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture

802.1AB-2005 IEEE Standard for Local and metropolitan area networks -- Station and Media Access Control Connectivity Discovery

802.2-1998 IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 2: Logical Link Control

802.3-2005 IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications

802.11-2007 IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

802.15.1-2005 IEEE Standard for Information Technology - telecommunications and information exchange Systems between systems - Local and metropolitan area networks-Specific requirements - Part 15.1a: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for Wireless Personal Area Networks (WPAN)

802.15.4-2006 IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPANs)

802.16-2009 IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Broadband Wireless Access Systems

802.20-2008 IEEE Standard for Local and Metropolitan Area Networks - Part 20: Air Interface for Mobile Broadband Wireless Access Systems Supporting Vehicular Mobility -- Physical and Media Access Control Layer Specification

1588-2008 IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

1675-2008 IEEE Standard for Broadband over Power Line Hardware

1453-2004 IEEE Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems

1459-2000 IEEE Standard Definitions for the Measurement of Electric Power Quantities under Sinusoidal Non-Sinusoidal Balanced or Unbalanced Conditions

C37.101-2006 IEEE Guide for Generator Ground Protection

C37.101-2006/Cor 1-2007 IEEE Guide for Generator Ground Protection - Corrigendum 1: Annex A.2 Phasor Analysis (Informative)

C37.102-2006 IEEE Guide for AC Generator Protection

C37.104-2002 IEEE Guide for Automatic Reclosing of Line Circuit Breakers for AC Distribution and Transmission Lines

C37.106-2003 IEEE Guide for Abnormal Frequency Protection for Power Generating Plants

C37.111-1999 IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems

C37.112-1996 IEEE Standard Inverse-Time Characteristic Equations for Overcurrent Relays

C37.114-2004 IEEE Guide for Determining Fault Location on AC Transmission and Distribution Lines

C37.115-2003 IEEE Standard Test Method for Use in the Evaluation of Message Communications Between Intelligent Electronic Devices in an Integrated Substation Protection Control and Data Acquisition System

C37.116-2007 IEEE Guide for Protective Relay Application to Transmission-Line Series Capacitor Banks

C37.117-2007 IEEE Guide for the Application of Protective Relays Used for Abnormal Frequency Load Shedding and Restoration

C37.118-2005 IEEE Standard for Synchrophasors for Power Systems

C37.230-2007 IEEE Guide for Protective Relay Applications to Distribution Lines

C37.231-2006 IEEE Recommended Practice for Microprocessor-Based Protection Equipment Firmware Control

C37.232-2007 IEEE Recommended Practice for Naming Time Sequence Data Files

C37.90.2-2004 IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers

C37.91-2008 IEEE Guide for Protecting Power Transformers

C37.92-2005 IEEE Standard for Analog Inputs to Protective Relays From Electronic Voltage and Current Transducers

C37.93-2004 IEEE Guide for Power System Protective Relay Applications of Audio Tones Over Voice Grade Channels

C37.94-2004 IEEE Standard for N Times 64 Kilobit Per Second Optical Fiber Interfaces Between Teleprotection and Multiplexer Equipment

C37.95-2002 IEEE Guide for Protective Relaying of Utility-Consumer Interconnections

C62.11-2005 IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)

C62.11a-2008 IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1 kV) Amendment 1: Short-Circuit Tests for Station Intermediate and Distribution Arresters

81-1983 IEEE Guide for Measuring Earth Resistivity Ground Impedance and Earth Surface Potentials of a Ground System Part 1: Normal Measurements

81.2-1991 IEEE Guide for Measurement of Impedance and Safety Characteristics of Large Extended or Interconnected Grounding Systems

1127-1998 IEEE Guide for the Design Construction and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility

1379-2000 IEEE Recommended Practice for Data Communications Between Remote Terminal Units and Intelligent Electronic Devices in a Substation

1402-2000 IEEE Guide for Electric Power Substation Physical and Electronic Security

1615-2007 IEEE Recommended Practice for Network Communication in Electric Power Substations

1646-2004 IEEE Standard Communication Delivery Time Performance Requirements for Electric Power Substation Automation

1686-2007 IEEE Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities

C37.1-2007 IEEE Standard for SCADA and Automation Systems

C37.2-2008 IEEE Standard Electrical Power System Device Function Numbers Acronyms and Contact Designations

1247-2005 IEEE Standard for Interrupter Switches for Alternating Current Rated Above 1000 Volts

1325-1996 IEEE Recommended Practice for Reporting Field Failure Data for Power Circuit Breakers

C37.100-1992 IEEE Standard Definitions for Power Switchgear

644-1994 IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines

656-1992 IEEE Standard for the Measurement of Audible Noise from Overhead Transmission Lines

1250-1995 IEEE Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems

C57.120-1991 IEEE Loss Evaluation Guide for Power Transformers and Reactors

C57.123-2002 IEEE Guide for Transformer Loss Measurement

80-2000 IEEE Guide for Safety in AC Substation Grounding

367-1996 Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Indusced Voltage from a Power Fault

487-2007 Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Supply Stations

1590-2009 Recommended Practice for the Electrical Protection of Communication Facilities Serving Electric Supply Locations Using Optical Fiber Systems

A2. The existing Smart Grid-related standards identified by NIST

www.smatrgrid.gov/standards/existing, [24-12-2010]

1. **ANSI/ASHRAE 135-2008/ISO 16484-5 BACnet − A Data Communication Protocol for Building Automation and Control Networks**: Defines an information model and messages for building system communications at a customer's site. BACnet incorporates a range of networking technologies to provide scalability from very small systems to multi-building operations that span wide geographic areas using IP protocols.

2. **The ANSI C12 Suite**

a. **ANSI C12.1: Performance and safety tests for revenue meters**: Performance and safety type tests for revenue meters.

b. **ANSI C12.18: Protocol and optical interface for measurement devices**: Protocol and optical interface for measurement devices.

c. **ANSI C12.19/MC1219: Revenue-metering end device tables:** Revenue metering end device tables.

d. **ANSI C12.20: Revenue-metering accuracy specification and type tests**: Revenue metering accuracy specification and type tests.

e. **ANSI C12.21: Transport of measurement device data over telephone networks**: Transport of measurement device data over telephone networks.

3. **ANSI/CEA 709 and CEA 852.1 LON Protocol Suite**

a. **ANSI/CEA 709.1-B-2002 Control Network Protocol Specification: Physical-layer protocol:** A general-purpose local area networking protocol in use for various applications, including electric meters, street lighting, home automation, and building automation.

b. **ANSI/CEA 709.2-A R-2006 Control Network Power Line (PL) Channel Specification: Physical-layer protocol**: A specific physical layer protocol designed for use with ANSI/CEA 709.1-B-2002.

c. **ANSI/CEA 709.3 R-2004 Free-Topology Twisted-Pair Channel Specification**: A specific physical layer protocol designed for use with ANSI/CEA 709.1-B-2002.

d. **ANSI/CEA-709.4:1999 Fiber-Optic Channel:** A specific physical layer protocol designed for use with ANSI/CEA 709.1-B-2002.

e. **CEA-852.1:2009 Enhanced Tunneling Device Area Network Protocols Over Internet Protocol Channels:** Provides a way to tunnel local operating network messages through an IP network using the User Datagram Protocol, thus providing a way to create larger internetworks.

4. **DNP3**: Used for substation and feeder device automation as well as for communications between control centers and substations.

5. **IEC 60870-6/TASE.2**: Defines the messages sent between control centers of different utilities.

6. **IEC 61850 Suite:** Defines communications within transmission and distribution and substations for automation and protection; being extended to cover communications beyond the substation to integration of distributed resources and between substations.

7. **IEC 61968/61970 Suites:** These families of standards define information exchanged among control center systems using common information models. They define application-level energy management system interfaces and messaging for distribution grid management in the utility space.

8**. IEEE C37.118:** Defines phasor measurement unit performance specifications and communications.

9. **IEEE 1547 Suite:** Defines physical and electrical interconnections between utility and distributed generation and storage.

10. **IEEE 1588:** For time management and clock synchronization across the smart grid for equipment needing consistent time management.

11**. Internet Protocol Suite, including but not limited to IETF RFC 2460 (IPv6):** Foundation protocol for delivery of packets in the Internet network.

12. **Multispeak:** For application software integration within the utility operations domain; a candidate for use in an enterprise service bus.

13. **OpenADR:** Defines messages exchanged between utilities and commercial/industrial customers for price-responsive and direct load control.

14**. OPC-UA Industrial**: Platform-independent specification for a secure, reliable, high-speed data exchange based on a publish/subscribe mechanism.

15. **Open Geospatial Consortium Geography Markup Language:** For exchange of location-based information addressing geographic data requirements.

16. **ZigBee/HomePlug Smart Energy Profile 2.0:** Home area network device communications and information model.

17. **OpenHAN:** For home area network connection to the utility advanced metering system, including device communication, measurement, and control.

18. **AEIC Guidelines v2.0**: Framework and testing criteria for vendors and utilities for standards-based advanced metering infrastructure solutions.

19. **Security Profile for Advanced Metering Infrastructure, v 1.0:** Provides guidance and security controls for advanced metering infrastructure solutions; includes meter data management system up to and including the home area network interface of the smart meter.

20. **Department of Homeland Security, National Cyber Security Division, 2009 September Catalog of Control Systems Security Recommendations for Standards Developers**: Compilation of recommended practices to increase control system security from physical and cyber-attacks.

21. **Department of Homeland Security Cyber Security Procurement Language for Control Systems:** Guidance for procuring cyber security technologies for control systems products and services.

22**. IEC 62351 Parts 1-8**: Defines information security for power system control operations.

23**. IEEE 1686-2007:** Covers intelligent electronic device security capabilities, including the access, operation, configuration, firmware revision, and data retrieval.

24. **NERC CIP 002-009**: Standards covering physical and cyber security standards for the bulk-power system.

25. **NIST Special Publication (SP) 800-53, NIST SP 800-82:** Standards for cyber security and guidelines for federal information systems, including those for the bulk-power system.

A3. IEEE Smart Grid Standards in Development

http://smartgrid.ieee.org/standards/ieee-smartgrid-standards-in-development, [26-12-2010]

P2030 Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads

P802 IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture

P802.11 IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks -

Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

P802.15.4g IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPANs) - Amendment: Physical Layer (PHY) Specifications for Low Data Rate Wireless Smart Metering Utility Networks

IEEE 802.16's GRIDMAN Study Group (Greater Reliability In Disrupted Metropolitan Area Networks)

P1815 Standard for Electric Power Systems Communications - Distributed Network Protocol (DNP3) Working Group website

P1377 Standard for Utility Industry Metering Communication Protocol Application Layer Standard (End Device Data Tables)

SCC31 Automatic Meter Reading and Energy Management

P1701 Standard for Optical Port Communication Protocol to complement the Utility Industry End Device Data Tables

P1702 Standard for Telephone Modem Communication Protocol to complement the Utility Industry End Device Data Tables

P1703 Standard for Local Area Network/Wide Area Network (LAN/WAN) Node Communication Protocol to complement the Utility Industry End Device Data Tables

P1901 Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications

P1775 Standard for Powerline Communication Equipment - Electromagnetic Compatibility (EMC) Requirements - Testing and Measurement Methods

P1020 Guide for Control of Small (100 kVA to 5 MVA) Hydroelectric Power Plants

P1595 Standard for Quantifying Greenhouse Gas Emission Credits from Small Hydro and Wind Power Projects and for Grid Baseline Conditions

P1797 Guide for Design and Application of Solar Technology in Commercial Power Generating Stations

P1777 Recommended Practice for Using Wireless Data Communications in Power System Operations

P1459 Standard Definitions for the Measurement of Electric Power Quantities under Sinusoidal Non-Sinusoidal Balanced or Unbalanced Conditions

PC37.104 Guide for Automatic Reclosing of Circuit Breakers for AC Distribution and Transmission Lines

PC37.111 Standard for Common Format for Transient Data Exchange (COMTRADE) for Power Systems

PC37.118 Standard for Synchrophasors for Power Systems

PC37.236 Guide for Power System Protective Relay Applications over Digital Communication Channels

PC37.237 Recommended Practice for Time Tagging of Power System Protection Events

PC37.238 Standard Profile for Use of IEEE Std. 1588 Precision Time Protocol in Power System Applications

PC37.239 Standard Common Format for Event Data Exchange (COMFEDE) for Power Systems

PC37.95 Guide for Protective Relaying of Utility-Consumer Interconnections

PC62.11 Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)

PC62.39 Standard for Test Methods for Self-Restoring Current Limiter Components used in Telecommunication Surge Protectors

P81 Guide for Measuring Earth Resistivity Ground Impedance and Earth Surface Potentials of a Grounding System

P1031 Guide for the Functional Specification of Transmission Static Var Compensators

1127a IEEE Guide for the Design Construction and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility - Amendment to remove references to Substation Slide Library

P1711 Trial Use Standard for a Cryptographic Protocol for Cyber Security of Substation Serial Links

P1250 Guide for Identifying and Improving Voltage Quality in Power Systems

P1409 Guide for the Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV through 38 kV

P1695 Trial-Use Guide for Assessing Voltages at Publicly and Privately Accessible Locations

PC57.123 Guide for Transformer Loss Measurement

Appendix B

Mfgr.	DS-2					Atheros (Intellon)		Xeline	Arkados	YITRAN
Product	DSS9002	DSS9001	DSS9101	DSS9503	DSS9501	INT6300	INT5500	Xeus	AI-1100	ITM10
Standard / Alliance	OPERA	OPERA	OPERA	OPERA	OPERA	HomePlug AV	HomePlug Turbo	KSX4600-1	HomePlug 1.0	
Category	Access / AMI	Access	In-Home	In-Home / AMI	In-Home / AMI	In-Home	In-Home	Access & In-Home	In-Home	Access
Logical speed	240M	240M	200M	200M	200M	200M	85M	24M	28M	24M
Actual speed	120M	120M	100M	100M	100M	100M	20~25M	14M-UDP 8M-TCP	8M	12M
Frequency	2~32M / Selectable and customization					2~30M	4.3~20.9M	2~23M	4.3~20.9M	3~30M
Access method	TDMA	TDMA	TDMA	TDMA	TDMA	TDMA & CSMA/CA	CSMA/CA	CMAC	CSMA/CA	CSMA/CA
Modulation method	OFDM	OFDM	OFDM	OFDM	OFDM	OFDM	OFDM	PSK based DMT	OFDM	SS
Encryption	3DES	3DES	256b AES	256b AES	256b AES	128b AES	56b DES	56b DES	56b DES	56b DES
AFE	DSS7700	DSS7700	DSS7800	DSS7800	DSS7800	Include	INT1200	Exclude	Exclude	Exclude
QoS	8 Level	8 Level	8 Level	8 Level	8 Level	8 Level	4 Level	4 Level	4 Level	4 Level
SNMP	Yes	Yes	Yes	Yes	Yes	API only	API only	Yes	?	Yes
UART	1 port	1 port	1 port	1 port	1 port	1 port	None	1	?	None
Repeating	Yes	Yes	Yes	Yes	Yes	None	None	Yes	?	Yes
Power cons.	8W	6.5W	4.5W	5.1W	3.1 / 1.6W	5W	2W	1.5W	?	5.5W
Released	2004	2004	2007	2010	2009	2007	2005	2005	2006	2007

Table B1: Characteristics of current PLC solutions [20]

Technology	Simplicity of deployment	Spectrum Usage	Capacity Shared?	Symmetry	Capacity	Max Range	Strengths	Weaknesses
FIXED LINE								
HFC	Easy if a cable TV network already exists. Expensive if it is necessary to deploy the network	5-1000 MHz, 6-8 MHz/channel	Yes	Asymmetric.	USA: 3 - 4 Mbps Canada: up to 10 Mbps UK: 1 - 8 Mbps France: up to 100 Mbps Switzerland: up to 6 Mbps	Up to 100 km using amplifiers	Uses existing cable TV networks	Limited bandwidth and asymmetric
ADSL	Easy where existing POTs can be used	Up to 1.1 MHz	No	Asymmetric.	From 1,5 Mbps (5.4 km) to 12 Mpbs (300 m)	Up to 5.4 km	Uses existing POTs	Distance sensitive, asymmetric and distance sensitive
VDSL	Easy where existing POTs can be used	Up to 1.1 MHz	No	Asymmetric	From 13 Mbps (1.3 km) to 52 Mpbs (300 m)	Up to 1.3 km	Mainly uses existing POTs	Bandwidth is very distance sensitive. Requires fibre feeds
ADSL2+	Easy where existing POTs can be used	Up to 2.2 MHz	No	Asymmetric	From 7.5 Mbps (2.7 km) to 26 Mpbs (300 m)	Up to 2.7 km	Uses existing POTs	Bandwidth is distance sensitive
PLC	Easy. No new wiring needs.	1-30 MHz	Yes	Symmetric	200 Mbps shared medium 2 - 4 Mpbs per user	Up to 3 km in Medium Voltage Up to 200 m in Low Voltage	Uses existing power grid	No standards available
FFTH	Difficult. Requires new fibre access network overlay	T Hz	PON: Yes P2P: No	Symmetric	Up to 1 Gbps per channel per fibre	20 km	Very high bandwidth	Expensive deployment of the network

Table B2: Broadband Fixed Line Technologies Comparison

Technology	Simplicity of deployment	Spectrum Usage	Capacity Shared?	Symmetry	Capacity	Max Range	Strengths	Weaknesses
WIRELESS								
Microwave	Difficult. LOS needed	2, 4, 6, 21.3 –23.6 GHz > 40 GHz UHF(Licensed)	Yes	Symmetric	Up to 155 Mbps per Link	5 km	Quick setup	LOS Point to Point
LMDS	Difficult. LOS needed	28 – 31 GHz (Licensed)	Yes	Symmetric	Up to 155 Mbps per Link	4 km	Point to multipoint Large capacity	LOS Not standardized
MMDS	Difficult. LOS needed	2.1 – 2.7 GHz (Licensed)	Yes	Symmetric	Up to 10 Mbps per BE	100 km	Point to multipoint NLOS and long range	Low capacity Not standardized
FSO	Difficult. LOS needed	Infra-red THz region of spectrum (Unlicensed)	Yes	Symmetric	Up to 2.5 Gbps per link	4 km	Low setup cost Unlicensed spectrum	LOS Performance is weather sensitive
WiFi	Easy for LAN environment	2.4, 5.7 GHz (Unlicensed ISM bands ISM: Industry, Scientific and Medical)	Yes	Symmetric	Depending on standard: 2, 11, 54 Mbps	100 m	Ethernet compliant. Standardize.	For LAN applications only Security
WIMAX	Easy. NLOS needed.	2 to 11 GHz (licensed) 10 to 66 GHz (unlicensed)	Yes	Symmetric	Up to 70 Mbps	Up to 50 km	NLOS to be standardized	Practical bitrate2 Mbps NLOS limited to 1 – 2 km
Satellite	Easy but expensive	Ku-, Ka-,C-, L and S-band 1.5~3.5, 3.7~6.4, 11.7~12.7, 17.3~17.8, 20~30 GHz(Licensed)	Yes	Asymmetric	Up to 155 Mbps downlink	1000 - 36.000 km	Large coverage Suitable for multi cast applications	Expensive to build Limited capacity per subscriber
3G	Easy.	1.92 – 1.98 GHz 2.11 – 2.17GHz	Yes	Symmetric	Up to 2 Mbps per mobile	Mobile Coverage area	Mobile terminals Ride on existing cellular infrastructure	Costly spectrum Limited applications

Table B3: Broadband Wireless Technologies Comparison

	Technology	Normalization/ Standardization	Physical medium	Topology	Terminals	Range
Wireless technologies	Satellite	DVB, ETSI	Radio, 11-14 GHZ, (Ku), 20-30 GHz (Ka)	Multipoint	Fixed (also mobile with low kbit/s)	Line of Sight
	UMTS	3GPP	Radio, 1.7-2.2 GHz	Multipoint	Mobile	50 m-3 km
	WLAN	IEEE 802.11, ETSI	Radio, 2.4 GHz (.11b and .11g), 5 GHz (.11a)	Multipoint	Mobile	50-150 m
	DTT	DVB, ETSI	Radio (UHF)	Multipoint	Fixed	32 km
	LMDS/ WiMax	IEEE 802.16, ETSI	Radio, 3 GHz, 26 GHz and above	Multipoint	Fixed	Line of Sight, 3 km (26 GHz), 8 km (3.5 GHz)
Fixed line technologies	HFC	DOCSIS, DVB	Fiber and coaxial	Multipoint	Fixed	40 km
	FTTX	FSAN, ITU-T	Optical fiber w/o twisted cooper line	Point-to-point or multipoint	Fixed	20 km
	xDSL	ITU-T, ETSI	Twisted pair	Point-to-point	Fixed	300 m-6 km
	PLC	PLC Forum, CENELEC, ETSI, IEEE	Medium and low voltage powerlines	Multipoint	Fixed	200 m (in low voltage)
	EFM	IEEE 802.3ah	Twisted pair or fiber	Point-to-point or multipoint	Fixed	750 m-2.7 km (using twisted pair)

Table B4: Broadband Wireless and Fixed Line Technologies Comparison

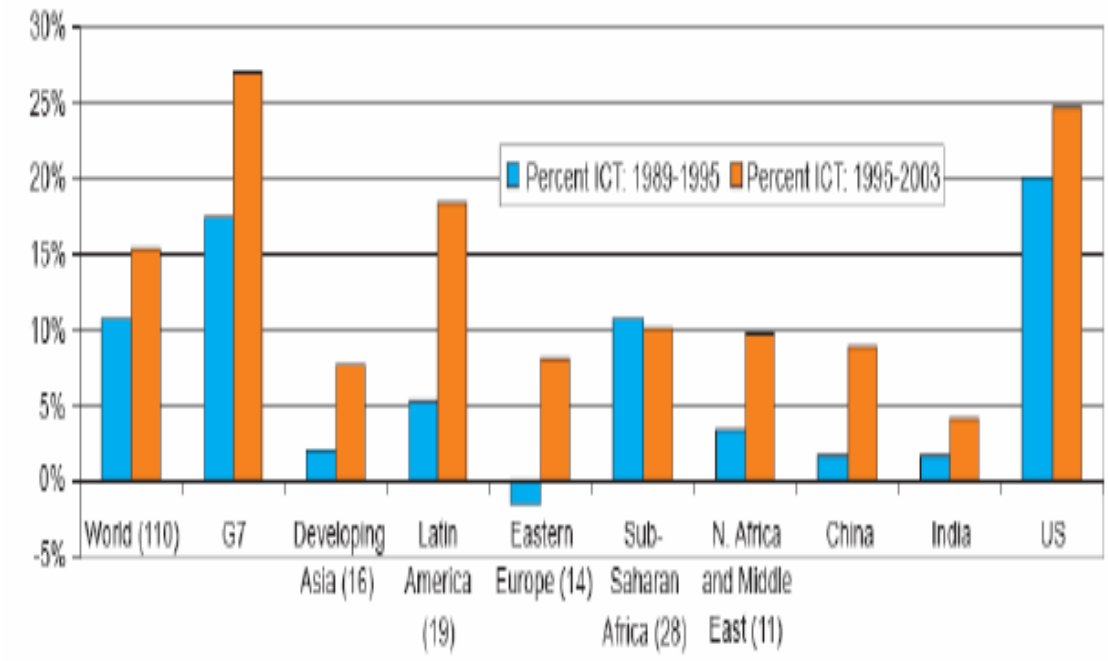

Table B5: ICTs contribution to economic growth

	Population (millions)	Rural population (%)	Rural population (millions)	Number of localities (000s)	Average size
Developing	**5'108**	**56%**	**2'850**	**2'961**	**1'826**
East Asia & Pacific	1'717	58%	1'000	956	1'795
Europe & Central Asia	446	33%	148	285	2'841
Latin America & Caribbean	529	21%	113	349	1'645
Middle East & North Africa	308	42%	129	107	2'961
South Asia	1'354	72%	977	868	1'560
Sub-Saharan Africa	754	64%	484	396	1'904
Developed	**1'013**	**22%**	**228**	**248**	**4'092**
World	**6'145**	**50%**	**3'102**	**3'059**	**2'009**
Developing as % of world	**84%**		**93%**	**92%**	

Table B6: Global Rural Population and Localities Estimation

Authorized PLC Transmission Bands (MHz) by FCC Regulations	Excluded PLC Transmission Bands (MHz) by FCC Regulations
1.705 to 2.850	2,850 to 3,025
3.025 to 3.400	3,400 to 3,500
3,500 to 4,650	4,650 to 4,700
4,700 to 5,450	5,450 to 5,680
5,680 to 6,525	6,525 to 6,685
6,685 to 8,815	8,815 to 8,965
8,965 to 10,005	10,005 to 10,100
10,100 to 11,275	11,275 to 11,400
11,400 to 13,260	11,260 to 13,360
13,360 to 17,900	17,900 to 17,970
17,970 to 21,924	21,924 to 22,000
22,000 to 74,800	74,800 to 75,200
75,200 to 80,000	

Table B7: Authorized and Excluded PLC Transmission Bands [7]

PLC Frequency Band	Amateur Radio
1,705 to 2,850	160meter
3,500 to 4,650	80meter
4,700 to 5,450	60meter
6,685 to 8,815	40meter
10,100 to 11,275	30meter
13,360 to 17,900	20meter
17,920 to 21,924	17 - 15meter
22,000 to 74,800	12 – 10 - 6meter

Table B8: Overlapping frequencies [6]

Location and Number of Residents	Location and Number of Residents	Estimated Number of KWh per Year	Estimated Annual Electricity Cost for Streetlights	Estimated Annual CO2 Emissions due to Streetlights (in tons)
U.S.	> 68 million	> 300 billion	> $18 billion	> 150 million
European Union	> 90 million	> 450 billion	> $45.5 billion	> 180 million
U.K.	7.5 million	> 4 billion	> $650 million	> 1.9 million
France	8.6 million	5.3 billion	$520 million	583,000
Los Angeles (U.S.)	220,000	> 100 million	> $17 million	> 60,000
Paris (France)	170,000	> 80 million	> $10.2 million	> $10.2 million

Table B9: Annual Electricity Consumption- Price-CO2 Emissions-Per Country/Town Estimation